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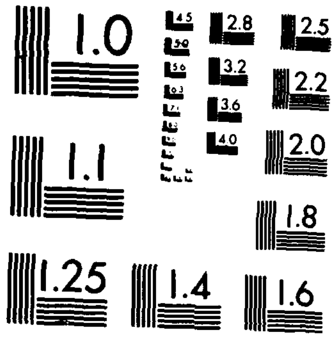

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A DESCRIPTION OF THE FAILURE
DISTRIBUTIONS OF SELECTED MINUTEMAN III
GUIDANCE SYSTEM ELECTRONIC CARDS

THESIS

Albert E. Sisk
Captain, USAF

AFIT/GLM/LSM/86S-76

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AFIT/GLM/LSM/86

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The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information is contained therein. Furthermore, the views expressed in the document are those of the author and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

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GUIDANCE SYSTEM ELECTRONIC CARDS

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

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Master of Science in Logistics Management

Albert E. Sisk, B.S.

Captain, USAF

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Abstract

This research described the failure distributions of selected Minuteman III guidance system electronic cards and was the first attempt to use the Total Time on Test graphical technique to detect failure patterns. The data analysis was performed by using a Zenith 100 computer program that performed the Total Time on Test calculations and the Reliability Data Acquisition and Analysis Techniques software package.

The objectives of the research were to 1) describe the failure distributions of selected Minuteman III electronic cards, 2) determine if the corresponding hazard function demonstrated infant mortality, useful life, or wearout, and 3) suggest management strategies to deal with wearout or infant mortality.

Five individual cards were selected and the first three lifetimes of each card were examined. Nine of the fifteen cards indicated an exponential failure distribution, the other six were identified as either a Weibull or a normal failure distribution.

The results of this research indicate that some of the lifetimes did show signs of wearout; however, it was determined that no management actions were required because of the large mean lifetimes of the cards affected.

A DESCRIPTION OF THE FAILURE DISTRIBUTIONS OF SELECTED MINUTEMAN III GUIDANCE SYSTEM ELECTRONIC CARDS

I. Introduction

Background

The reliability of military systems after long periods of dormancy has been a major concern throughout military history. A system which is taken out of storage is expected to complete its mission without performance degrading malfunctions. As military systems continue to become more complex, their expected response time has also shortened. To meet these requirements, reliability must increase. Newer missile systems are being developed, as much as possible, to be deployed as "wooden rounds." In other words, the system would require very minimal field level maintenance. Any corrective maintenance would be accomplished at depot level. This concept would deliver the missile to the operational unit as an "all up round" (totally assembled) and would require no installation of any parts, components, or subsystems. This concept applies to the missile only, not to any launch support system or launch platform (19:7).

The Minuteman Intercontinental Ballistic Missile (ICBM) weapon system has been deployed in its role of strategic nuclear deterrence since the early 1960s. When it was first deployed as the Minuteman I, its guidance system had a typical lifetime (mean time between failure [MTBF]) of approximately 600 hours (15:122). Since that time the Minuteman II and the Minuteman III versions of the weapon system have been deployed. The Minuteman III version now has a MTBF on the guidance system in excess of 10,000 hours (11:124). In other words, the Minuteman guidance system reliability improvement has gone from more than one failure per month per site to one failure every fifteen months per site. The Minuteman II system is currently undergoing a major modification that will allow it to meet or exceed the MTBF standard established by the Minuteman III. These improved MTBF standards are being established by a weapon system that was designed during the 1950s and was expected to function for only ten years. However, Minuteman has been deployed for more than 20 years and is currently scheduled to be on alert through the year 2000. This is indicative of what a reliability and maintainability enhancement program can achieve if given sufficient funds and management attention.

General Issue

The problem for this research is detecting if infant mortality, wearout, or useful life exists in electronic

components and its effect on the reliability and maintainability (R & M) of Air Force weapon systems. The emphasis on R & M is increasing because of the impact of R & M on weapon system readiness, as well as on operational and support costs. Many factors influence R & M; however, this research effort will focus on a method for detection of failure distributions in electronic cards of the Minuteman III guidance system. This is important because infant mortality increases maintainability costs and reduces reliability because of increased failures early in a system's life. Wearout, on the other hand, may limit readiness due to increased failures in a system's life.

Specific Problem

The research question is defined as detecting which failure distribution exists in specific Minuteman III guidance system electronic cards. The specific problem for this research is the identification of infant mortality, wearout, or useful life in Minuteman III guidance system electronic cards. Infant mortality is characterized by a decreasing rate of failure early in the life of a component or system. Wearout occurs when there is an increasing rate of failure late in the life of a component or system. Useful life is characterized by a constant rate of failure. The reliability of an item is the probability of that item being able to perform its function for a specific period of time in its environment. Stated simply, reliability is

the chance the item will work when it is supposed to. If failure rates are high, as in infant mortality, the chances of the item working when required are reduced. Traditional measures of reliability such as mean time between failures cannot signal infant mortality or wearout. For this reason, we need new methods of detecting these problems. There has been much research done on methods of detecting various failure modes and the one that this research effort will use is the Total on Test (TTT) graphical technique.

Research Objectives

The objectives of this research effort are to:

1. Describe the failure distributions of electronic cards in the Minuteman III guidance system.
2. Determine if the corresponding hazard function demonstrates infant mortality, wearout, or useful life.
3. Suggest management strategies for reducing any infant mortality in the Minuteman III guidance system, and if evidence of wearout exists, suggest preventive maintenance strategies for management consideration.

This portion of the thesis introduced the subjects of reliability, maintainability, infant mortality, wearout and useful life. Methods for detecting infant mortality, wearout, and useful life were identified. We have also discussed the specific problem for this research —

detecting infant mortality, wearout, or useful life in certain electronic cards in the Minuteman III guidance system. The next portion of the thesis will discuss some of the pertinent literature available on these topics.

II. Literature Review

This portion of the thesis will examine some of the literature on the types of failure characteristics and their impact on weapon system readiness. We focus on the reliability topics of decreasing, constant, and increasing hazard functions, as well as the total times on test transform technique which is a useful graphical representation of the hazard function. Our interest in the hazard functions is motivated by a recognition that management policy can offset the negative effects of infant mortality or wearout without resorting to expensive redesign.

Hazard Functions

The hazard function is defined as the probability of failure in a finite interval of time. It is the instantaneous failure rate at age t. The hazard function is a measure of proneness to failure as a function of age and is used by life insurance companies to forecast human mortality (14:25). Halley's mortality table is illustrated in Figure 1 as an example of a hazard function and demonstrates that as age initially increases, the hazard function decreases. Then as age increases, so does the hazard function (14:25).

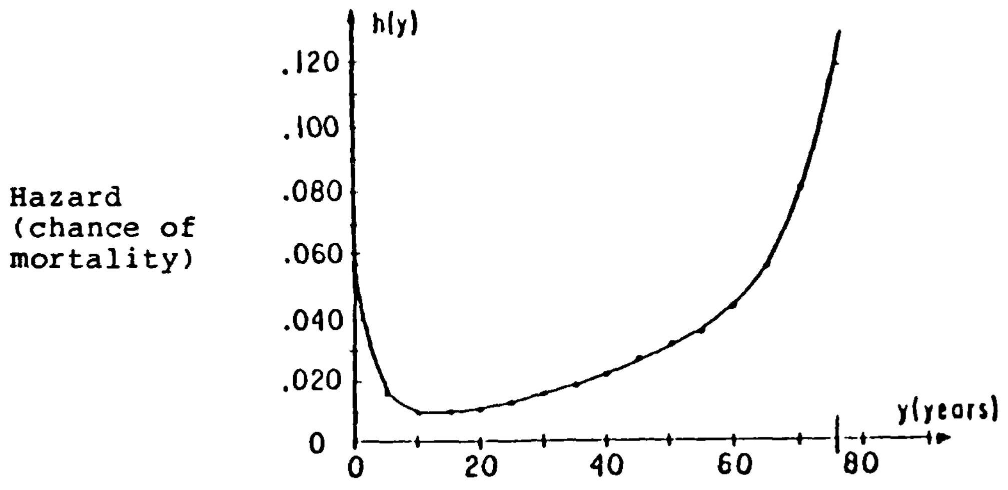

Figure 1. Halley's Mortality Table Hazard Function (14:25)

This research is concerned with finding whether or not the hazard function of a particular group of electronic cards from the Minuteman guidance system increases or decreases with age.

Hazard Plots

The hazard plot can be used for checking failure distributions and can provide a quick method for estimating distribution parameters, the percentage of components failing by a certain age, percentiles of the distribution, the failure rate of the components as a function of their age, and conditional failure probabilities for units of any age (2:113).

Bathtub Curve

The bathtub curve, as illustrated in Figure 2, is generally used to illustrate three hazard functions: decreasing, constant, and increasing. Some products will have a decreasing hazard function early in life and an increasing hazard function as the age of the product increases (14:26). If a decreasing hazard function is present, management actions, such as the use of a burn-in period or environmental stress testing, can be initiated. These actions could lead to considerable time and cost savings because of the increase in useful life of an item.

A decreasing hazard function during the early life of an item is often called infant mortality. It often occurs as a result of poorly designed items, improper manufacturing techniques, or misuse (11:203). Some

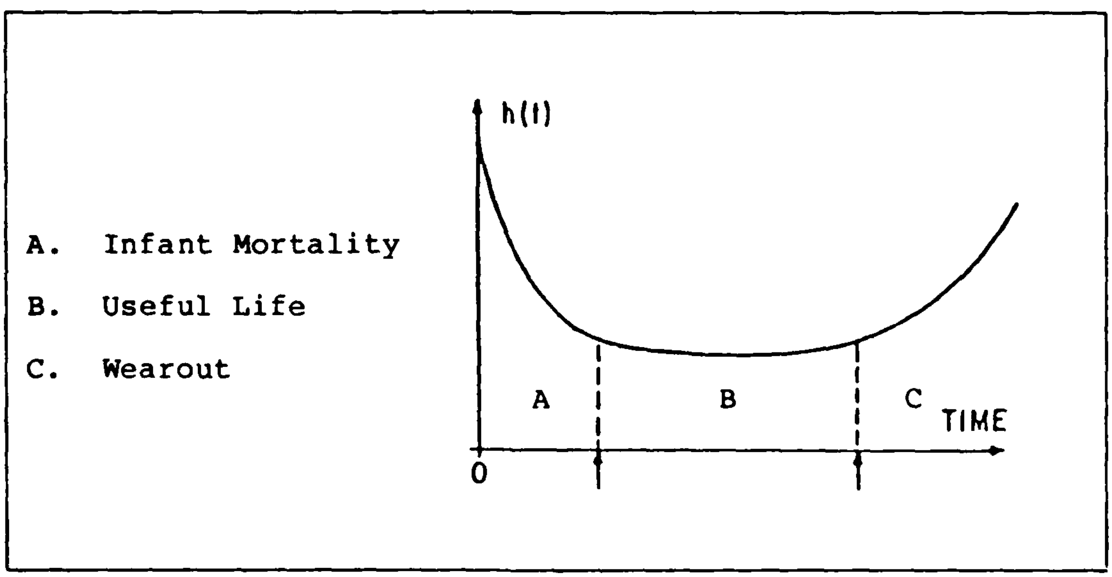

Figure 2. Bathtub Curve (14:27)

electronic components are subjected to a burn-in process to reduce infant mortality effects prior to being put into service. When this burn-in is accomplished, the components ideally enter service in the lowest portion of the hazard function and the reliability of the components is increased (14:26). This portion of a component's life is also referred to as useful life (9:26). During the component's useful life, the hazard function is essentially constant and the exponential distribution can be used to describe its life.

An increasing hazard function during the component's life can be said to correspond to wear-out failure. Such hazard functions often indicate that failures are due to the product wearing out (14:26). If wearout is indicated, preventive maintenance strategies may be considered by management to improve reliability.

Total Time on Test Plot

The failure of a component may, in many situations, be costly and possibly even dangerous. In the case of the components being examined, a failure is obviously costly in terms of weapon system readiness, as well as the manhours required to repair the component. If this research is able to determine that used units are more prone to failure than newer ones, perhaps it may be to our benefit to replace a used component after a certain period of time (7:467).

Barlow and Campo developed a method that aids in the determination of the failure distribution of an item using observed data (4:451-481). Their technique is called the Total Time on Test Plot (TTT) and graphically represents a transform of the empirical failure distribution for the item being examined. The data is ranked from shortest to longest lifetime and the total time on test statistic is calculated as

$$T(X_{(i)}) = \sum_{j=1}^{i} (n-1+j)\ (X_{(j)} - X_{(j-1)}) \qquad (2.1)$$

where

$i = 1,2,...n$

n = the sample size

$T(X_{(0)}) = 0$

$T(X_{(i)})$ = the total time on test statistic, and

$X_{(i)}$ = the ith ordered lifetime.

Use of TTT plots allows easy identification of increasing failure rate (IFR) and decreasing failure rate (DFR) distributions. A constant failure rate distribution, or exponential distribution, is represented by a 45 degree line commencing at the origin and proceeding up and to the right. If the TTT plot identifies an IFR, the plot would be distinguished by its convex shape. In other words, the plot would bow away from the horizontal axis (i/n). The DFR is represented by a concave plot that bows toward the

horizontal axis (i/n) (4:451-481). This method of hazard rate identification will be used to analyze the Minuteman guidance system failure data obtained from Hill AFB, Utah. Table 1 shows the calculations necessary for the construction of an example TTT plot and the TTT plot is illustrated in Figure 3. The lifetimes used in Table 1 were ordered prior to accomplishing the computations. The computations were performed using Equation 2.1, the total time on test equation.

An important feature of the TTT plot is that it allows failure distribution analysis when only incomplete data are available. Incomplete data can be one of three types: 1) a grouped data, 2) truncated data, and 3) censored data. Grouped data records failures in terms of a specific time period. Truncated data occurs when collection is terminated at an arbitrary time. Censored data involves

TABLE I

Calculations for Constructing a TTT Plot

ith Failure	$X_{(i)}$	$T(X_{(i)})$	U_i	i/n
1	5 hours	20 hours	.4	.25
2	10 hours	35 hours	.7	.50
3	15 hours	45 hours	.9	.75
4	20 hours	50 hours	1.0	1.00

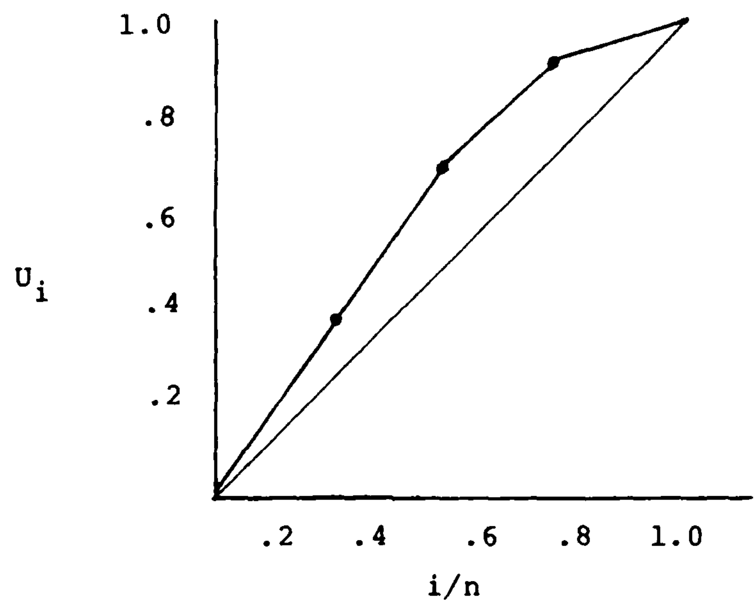

Figure 3. Sample TTT Plot Using Calculations from Table I

the termination of collection after a specific number of failures. Each of these types of data can be analyzed by modifying the TTT plot through the total time on test equation, Equation 2.1. However, the technique does have limitations. When actual data is used, sample size, removal of unfailed parts (withdrawal), and truncation can affect the results (4:451).

Barlow and Proschan identify tests that can be used to help identify the particular failure distribution when truncated data is used. An exponential distribution can be identified by a "crossings test"; how many times the plot crosses the 45 degree line (4:456). If the failure rate is

exponential and n is the number of failures, the probability of the TTT plot being entirely above or below the 45 degree line is 1/n. Another test is the total area between the TTT plot and the 45 degree line that is compared to a tabulated statistic (4:470). Barlow and Proschan also show that the TTT plot from a truncated sample will always be farther away from the 45 degree line than plots of the same size that come from complete data (4:472).

Truncations and withdrawals can also be dealt with by graphic estimation of a distribution and plotting of the TTT transform for the full sample size. Barlow and Proschan provide a review of failure processes and the normal, lognormal, gamma, and Weibull distributions (5:9-44).

Another tool used in this research to determine failure distributions is the Reliability Data Acquisition and Analysis Techniques (RDAAT) software package that is available for the Zenith 100 computer. The program was written for the Air Force by the BDM Corporation. The basic purpose of RDAAT is to establish a more accurate approach to reliability analysis using state-of-the-art statistical techniques. These techniques will provide more accurate reliability estimates of systems and line replaceable units (LRUs) by determining more accurate life predictions and providing insight into forecasting and manpower requirements (16:1,2).

Statistical inferences are made by identifying the best fit for the failure distribution of the data. The RDAAT program does this by applying goodness-of-fit test statistics and hazard plotting techniques to the data (16:5). The software will check the goodness-of-fit for the Weibull, normal, lognormal, exponential, exponential power, logistic, and extreme value distribution functions.

The basic tests used to check the fit of the curves generated are the Smith-Bain and Tiku goodness-of-fit tests that are in the RDAAT software package. Both of these tests are considered to be more powerful statistics than either the Chi-square or Kolmogorov-Smirnov goodness-of-fit tests when incomplete data is used (16:5; 18:261).

Failure Distributions

Failure distributions are attempts to describe mathematically the length of life of a material, structure, or a component. The modes of possible failure for the item in question will affect the form of the failure distribution (5:9).

A variety of distributions have been used to describe the life length of electronic and mechanical components. Here, we discuss the exponential and the Weibull distributions because of their applicability to this research. The exponential distribution is often used to describe useful life and the Weibull distribution is often used to describe infant mortality or wearout (14:27).

Exponential Failure Distribution

A characteristic of the exponential distribution is that it has an instantaneous failure rate that is constant over time. For example, the chance of failure for an old item that has not failed over a specified period of time is the same as that for an unfailed new item over the same length of time (14:26). While the exponential distribution has a number of desirable mathematical properties, its uses are limited because of the following property: it can be proven that if the life length of an item has the exponential distribution, previous use does not affect its future life length. The exponential distribution is the only distribution with this property (5:15).

The exponential distribution has been used as a model for the life of many components because this distribution describes components subject to chance failures. In other words, the probability of failure of an item is the same at any point in age. The exponential distribution may be used to describe the time between failures for items that can be repaired and is also used to describe produce life after units have gone through a burn-in up to the time they start to wear out (14:18). The exponential distribution consists of outcomes $t \geq 0$ and the probability density function (pdf)

$$f(t) = (1/\theta) \exp(-t/\theta), \; t \geq 0, \qquad (2.2)$$

where the parameter Θ (theta) is called the distribution mean, and must be positive. Θ is expressed in the same units as t, such as hours, cycles, years, etc. (14:18).

The mean of the exponential distribution is

$$E(X) = \int_0^\infty \exp(-x/\Theta)dx = \Theta \qquad (2.3)$$

This shows why the parameter Θ is called the mean time to failure (MTTF). In terms of the failure rate λ, $E(X)=1/\lambda$. When Θ is called the MTBF, it is being used to describe repairable equipment with exponentially distributed time between failures.

The reliability function R(x) for a life distribution is

$$R(x)=P(X>x\} = \int_x^\infty f(x)dx. \qquad (2.4)$$

This is the probability of a component surviving beyond age x. It is also called the survivorship function. Statisticians and actuaries have long worked with cumulative distributions for the fraction failing, but public relations minded engineers have turned them around and called them reliability functions (14:21).

The mathematical representation of the hazard function is

$$h(t) \equiv f(t)/R(t) \qquad (2.5)$$

and is the instantaneous failure rate at age t. It is also the ratio of the probability density function at time t to the probability of survival through the interval (0,t). The hazard function is also called the hazard rate, mortality rate, and the force of mortality (14:25).

Weibull Failure Distribution

The Weibull distribution has been found to be useful in a wide variety of applications, especially those that apply to product life. One of the reasons that this distribution has proved so popular is that it has a large number of shapes that make it very flexible in fitting data (14:36).

The literature suggests that this distribution may be used to describe single components that will cause a system failure (14:36). For example, the failure characteristics of a "weakest link" type of component could be described by the Weibull distribution. The electronic cards in the Minuteman III guidance system are a "weakest link" type of component. The failure of one of the electronic cards in the Minuteman III guidance system will cause a system failure.

The Weibull probability density function is

$$f(x) = (\beta/\alpha^{\beta})x^{\beta-1}\exp[-(x/\alpha)\beta], \ x>0. \tag{2.6}$$

The parameter β (beta) is called the shape parameter and is positive. The parameter α (alpha) is called the scale

parameter and is also positive. Alpha is in the same units as age x and beta is a dimensionless pure number (14:36).

For the special case of $\beta = 1$, the Weibull distribution is the exponential distribution. Figure 4 shows examples of Weibull probability densities with various shape parameters.

Figure 5 shows Weibull hazard functions. Note that the hazard function for $\beta = 1$ (the exponential distribution) is a constant failure rate, the hazard function for $\beta = .5$ is decreasing, and the hazard function for $\beta = 2$ is increasing. This ability to describe the various failure rates are why the Weibull distribution is popular for describing the lifetimes of data (14:39).

Reliability

Just as the tensions of the cold war continue to be a fact of life, weapon and space systems reliability has become a factor that influences the bargaining position of nations. If a war should start, weapon system reliability will help determine a nation's chance of survival. Electronics reliability is at the heart of the question because few weapons or space systems can reach their targets or objectives without reliable systems or subsystems (13:1). When reliability is considered from an economic viewpoint, high reliability is desired to reduce overall operations and support costs (1:3).

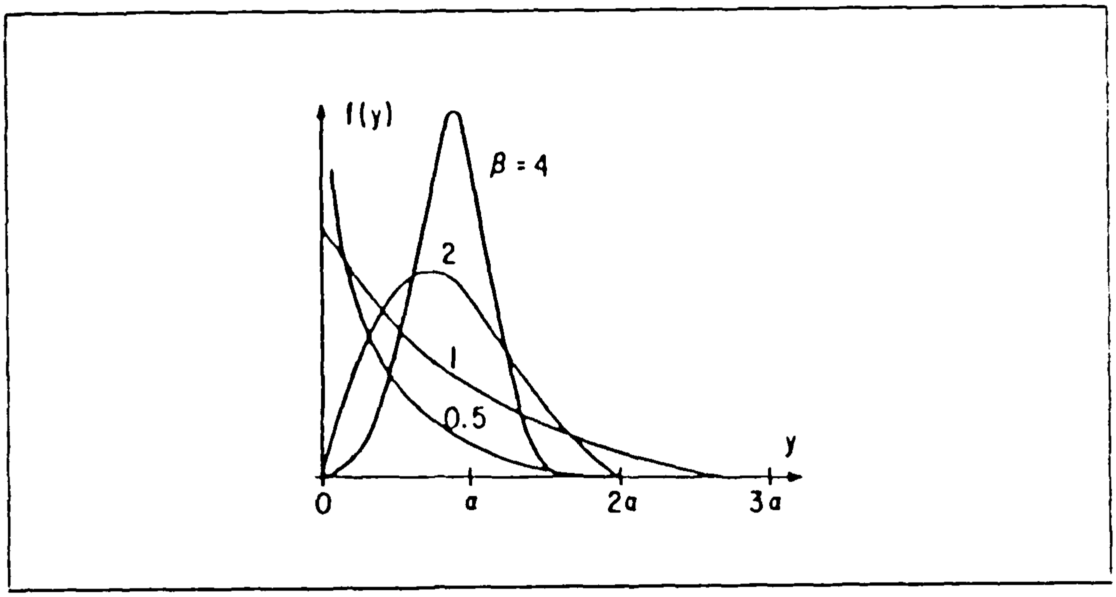

Figure 4. Weibull Probability Densities (14:37)

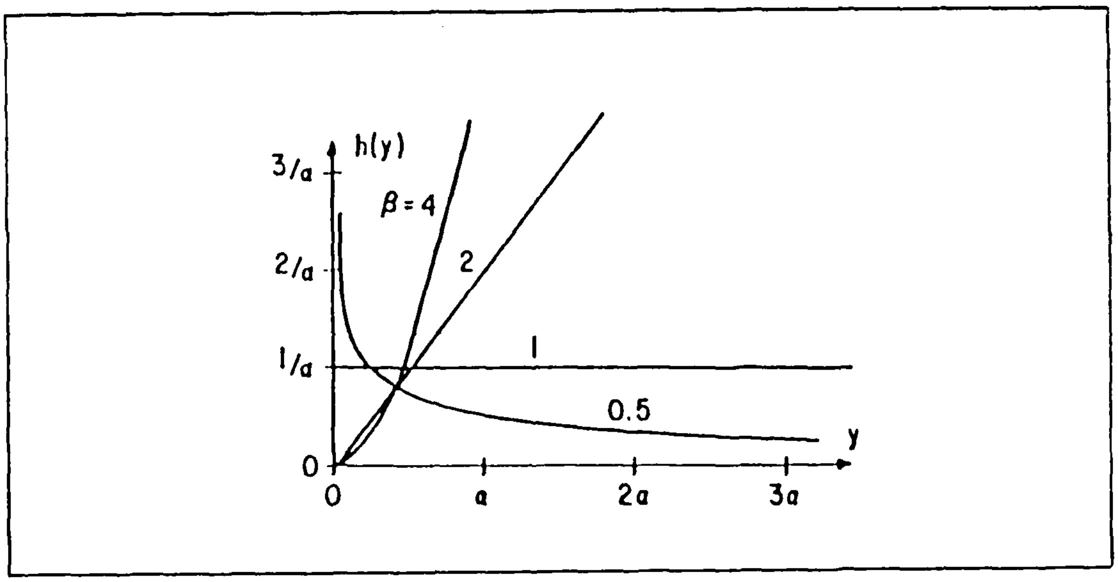

Figure 5. Weibull Hazard Functions (14:39)

A widely accepted definition of reliability is "the probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered." "This definition implies that reliability is the probability that the device will not fail to perform as required for a certain length of time" (6:22). In short, reliability is adequate performance over time; i.e., it is a measure of how long an item will operate before it fails. It is a straightforward concept that encompasses the ability to depend on something and is a necessary requirement for any operational equipment (12:24).

Maintainability Strategies

Like reliability, maintainability is an engineering discipline. It was developed to provide designers with a source of specialized skills and knowledge related to supporting and maintaining systems. The requirement came from the increasing complexity, size, and number of items that make up a system. As systems become more complex, they also become more costly to support and maintain (9:1).

The primary push for maintainability comes from the DOD and its military programs. However, general industry is also taking steps to advance this concept in support of their products and to help combat rising costs. The basic principles of the military specifications and standards of private industry are the same; they differ only in the particular needs of each user (9:4).

The objective of maintainability should be to design and develop complete systems that can be serviced in the least amount of time, cost, and with a minimum expenditure of support resources without affecting the performance or safety of the system (9:1). However, if there is evidence of wearout, then some preventive maintenance program may enhance the reliability and maintainability of a deployed system.

The study of reliability and maintainability has resulted in several methods for determining optimum preventive maintenance strategies for many types of components. Talbott (17:1-2) covers four strategies of preventive maintenance which are based on age and condition. The first strategy is age replacement. Age replacement is used when the age and condition of the system is known and is the replacement or repair of the item to an "as new" condition. This method replaces the item(s) of interest at failure and at a predetermined point in time without regard to the age of the item(s). Block replacement requires information about the item's condition, but not its age. These two conditions have the uncertainty of not knowing the item's lifetime. If failure cannot be detected except by inspection, then the item's condition is also unknown between inspections. The third maintenance strategy, called maintenance inspection, involves periodic inspection of the items at specific time intervals and replaces only

items that have failed. Talbott's last strategy is called blind replacement. This method replaces items without regard to their condition at a predetermined time interval and does not require inspection of the items between the time intervals. This method is practical if the cost of replacement is less than the cost of inspection. Talbott points out that a failed unit is not replaced at time of failure when using the last two methods and that these strategies should be considered for use only when failure of the item of interest is not fatal to the entire system (17:1-2).

In order for any of these strategies to be effective, the serviceability of the system should not be a factor. For example, a critical part that would be cheap to replace at specific time intervals should not be buried deep in the center of the system and take an excessive amount of time to replace.

Summary

This review examined the literature on reliability, maintainability, hazard functions, failure rates, and the total time on test method of graphically representing a hazard function. Planned maintenance strategies were also discussed. The strategies presented provide managers with four options to use in improving the reliability and maintainability of deployed systems.

The literature authored by Talbott, Barlow and Proschan, Barlow and Campo, and Bergman provided much of the direction for this research effort. Each author has provided substantial insight to the areas of reliability, maintainability, hazard functions and rates, and failure rate distributions. However, the total time on test statistic, introduced by Barlow and Campo and modified by Bergman, is used extensively in this research effort.

III. Methodology

This chapter describes the methods used to determine the failure distributions and corresponding hazard functions of the Minuteman III guidance system electronic cards that were selected for this research. Here we also describe the data used in this research, how the data was segregated by card type, the sampling plans used, and the computer program used to analyze the data. We also describe the particular location within the Minuteman III guidance system of the individual electronic cards selected for this research.

Particular Method

The general method of detecting infant mortality, wearout, or useful life in the electronic cards of the Minuteman III guidance system was done by computer analysis of lifetime failure data. Lifetime failure data were provided by the statistical analysis branch of the Material Management Engineering Division located at Ogden Air Logistics Center (OOALC/MMEAS). This group is located at Hill AFB, Utah, and their function is to do statistical analysis of Minuteman failure data. The data was sent to us in magnetic tape format.

The data were analyzed on a Zenith 100 Computer, utilizing a computer program written by Major John Kutzke,

an Air Force Institute of Technology (AFIT) instructor. The computer program was used to construct total time on test (TTT) plots of the failure data. A total time on test plot, which plots the total time on test or time exposed to risk versus calendar time, provided information about the failure rate function and assisted us in the determination of whether or not infant mortality, wearout, or useful life existed in the components being examined.

Burn-in periods and environmental stress testing are possible methods for dealing with infant mortality. The maintenance strategies discussed in Chapter II are possible methods for dealing with wearout. Both strategies are possible methods for improving system reliability.

Data Description

The data was provided by OOALC/MMEAS to the researcher on a magnetic tape configured in a 116-column record length, 30 records per block, 3480 blocks format. It was formatted at 5250 bytes per inch (BPI) and labeled in the Extended Binary Coded Decimal Interchange Code (EBCDIC) format. This format is not compatible with the magnetic tape reading equipment available for research support at AFIT. The tape was reformatted into a 116-column record length, 60 records per block, 6960 blocks, unlabeled, American Standard Code Information Interchange (ASCII) format. This format is compatible with the tape reading equipment available in the AFIT computer support area.

A sample of the data and the data format are contained in Appendix A. All of the data were configured sequentially by card type (alphabetically) and by serial number within each card type. Air Force Logistics Command (AFLC) Regulation 66-308, Attachment 3, provides a complete description of the data format.

Data was provided on 44 different types of electronic cards. The cards were from two main locations within the Minuteman III guidance system, the stabilized platform and the missile guidance set control. Five cards were selected for analysis, four are from the guidance set control, and the other is from the stabilized platform. These cards were selected because they had more than two lifetimes and had a large population. The card that was selected from the stabilized platform has started on its sixteenth lifetime. This card was selected so that we could examine those lifetimes for any changes in its failure distribution or mean lifetimes.

Data Selection

In preparation for analysis, the data was segregated into particular lifetimes by card type using a Fortran program prepared by the researcher. Each of these segregated lifetimes contained 1) electronic cards that had failed a certain number of times, and 2) electronic cards that had been temporarily removed from service for reasons other than failure, but had not yet failed again. For

example, all electronic cards that had experienced a single failure were sorted into one file, all electronic cards that had experienced two failures were sorted into another file, and so on until all available lifetimes were segregated. However, each of these files also contained entries for cards that had been temporarily removed form service for reasons other than failure. There were cards included in the data that had not yet experienced failure and they were also sorted into a segregated file. An example of a sorted data file containing failures and removals is shown in Table II.

Each of the segregated lifetimes was broken down into one file containing failures only, and another file that contained electronic cards that were removed for reasons other than failure. Each lifetime would therefore contain

TABLE II

Sorted Data File

Card Number	Serial Number	Hours	Failures	Hours Since Last Failure
BKM	988	61361	1	61631 (failure)
BKM	988	78120	2	16489 (failure)
BKM	988	82294	2	20663 (removal)
BKM	992	50954	1	50954 (failure)
BKM	992	81447	2	30493 (removal)

failures and temporary removals for reasons other than failure. Failures are identified as uncensored data and removals identified as censored data. The data was then analyzed using each card type's individual lifetimes as a separate group.

The Fortran programs in Appendix B were written by the researcher and used to separate all of the data into individual files. One program was used to separate all of the data into individual lifetimes, and each separation required that the program be changed to read a different file, write the new information to a different file, and read a different number of records. A different program was used to separate the electronic cards that had failures from those electronic cards that did not. This program is also included in Appendix B.

The columns of information selected from the entire data base for this research were the card type, item serial number, the cumulative operational hours, cumulative verified failures, and hours since last verified failure. The individual data files ranged in size from 2184 entries to 21 entries. Sampling levels and plans from Military Standard 105D, Table 7-1 and Table 7-2, were used to select the sample sizes from the individual data sets that had populations too large for the Zenith 100 to calculate. The sample sizes from Military Standard 105D were chosen because the standard has been proven to be mathematically

and statistically sound (10:1). Individual samples were selected from the large files by the use of random numbers from the random number table in the CRC Standard Mathematical Tables text. A sample of the random number table used is shown in Appendix C.

After all of the data was segregated into individual files, each file was printed in hard copy so that samples could be selected and all necessary data was readily available for input into the Zenith 100 computer. The data entered was the difference between the cumulative operational hours and the hours since the last failure. In the case of the electronic cards with no failures or only one failure, these hours represented cumulative operational hours until data selection was made. For the electronic cards with more than one failure, these hours represented the difference between the cumulative operational hours and the hours since last verified failure. The electronic cards that were used as censored data used the difference between the current removal hours and the last removal for a reason other than a failure. In many cases, individual cards had more than one removal between failures. The above process was repeated, when required, for each removal for reasons other than failure.

The program used by the Zenith 100 computer for data manipulation is Total Time on Test 1 (TTT1). The program is an adaptation of a Fortran program written by Lt Col

Carlos Talbott, HQ USAF/LE-RD, in support of his doctoral dissertation research. The program was rewritten in ZBASIC programming language by Major John Kutzke, AFIT/LSM, and modified by Captain William Rimpo and the researcher. A printout of the program is provided in Appendix D. The program performs all calculations required in support of the Total Time on Test Transform described in Chapter II of this thesis.

The data was input by individual lifetime into the Zenith 100 computer and calculations performed by the TTT1 program. When calculations are completed, the TTT1 program provides a data file that can be plotted using the Total Time on Test graphical technique. The data for this research was plotted using the GRAFTALK software that is available for the Zenith 100 computer. An example of the command formats used by the GRAFTALK software for this research is provided in Appendix E.

The GRAFTALK plots were used to perform a portion of the data analysis. The plots gave a visual indication of whether or not infant mortality, wearout, or useful life was occurring in the individual data file. The plots were also used in determining possible failure distributions for the individual data files. An example of a GRAFTALK plot is shown in Figure 6.

Another tool employed to assist the researcher in determining individual failure distributions was the

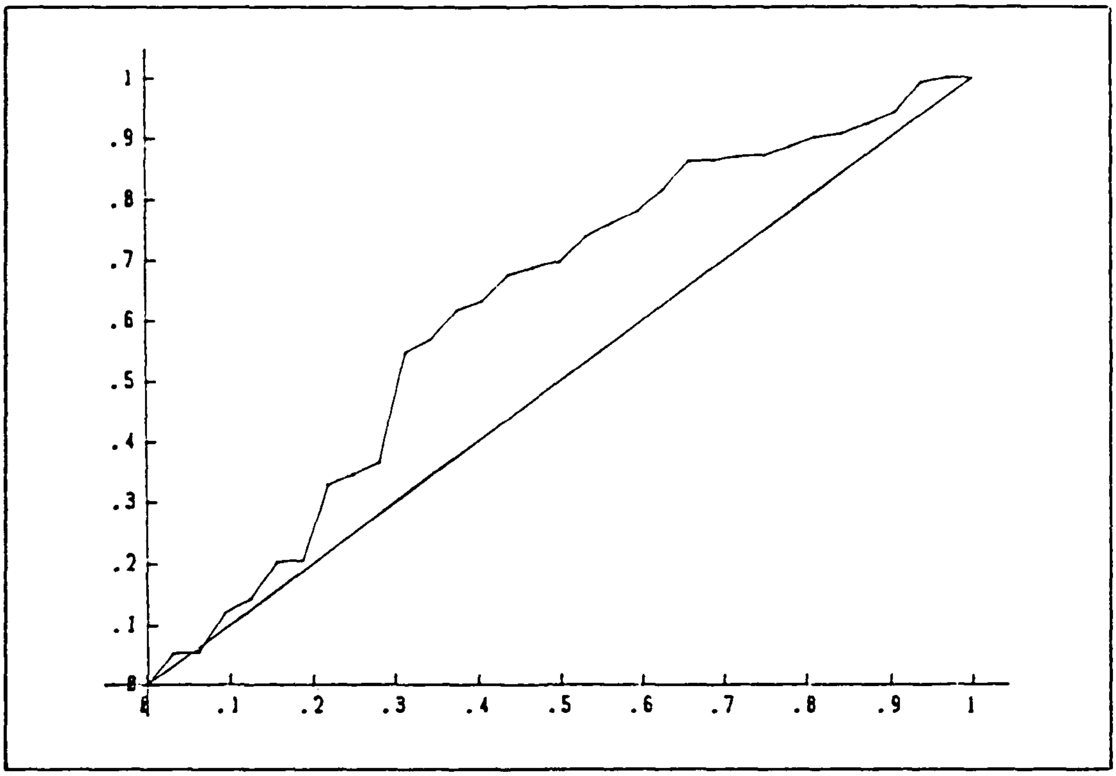

Figure 6. Sample GRAFTALK Plot

Reliability Data Acquisition and Analysis Techniques (RDAAT) program for the Zenith 100 computer. The program was written for the Air Force by the BDM Corporation. According to the BDM Corporation, the basic use for RDAAT is to establish a more accurate approach to reliability analysis using state-of-the-art statistical techniques (16:1-2). These techniques will provide more accurate reliability estimates of systems, and line replaceable units (LRUs) by determining more accurate life predictions and providing insight into forecasting and manpower requirements.

Five electronic cards were selected as subjects for this research. The cards that were selected are from the missile guidance set control, the x, y, and z ECA accelerometers, the 4.8 kilocycle power supply, the 400 cycles per second fan power supply, and the Minuteman III stabilized platform.

Summary

The results of these applied methods will allow us to complete the research objectives of describing the failure distributions of selected electronic cards in the Minuteman III guidance system and determine if the corresponding hazard functions demonstrate infant mortality, wearout, or useful life. By accomplishing these objectives, we will also answer the research question of whether or not infant mortality, wearout, or useful life exists in these electronic cards.

This portion of the research has explained the methodology used to reduce the initial data file into segregated lifetimes so that an analysis could be performed on each lifetime to determine: 1) if a particular failure distribution is present, 2) if infant mortality or wearout is present, or 3) if the lifetime is in useful life. The next chapter of this research will report the results of the data analysis, give a graphical representation of the identified failure distribution, and report on the results of the RDAAT statistical analysis.

IV. Results

This portion of the research reports the results of the data analysis performed using the total time on test graphical method and the Zenith 100 computer RDAAT statistical program. We report the failure distribution, hazard function, and indicated lifetime pattern for each of the five types of electronic cards examined. This research examined the first three lifetimes of each of the five card types for the indicated failure distribution, hazard function and lifetime pattern. The results will be reported in lifetime order by particular card type serial number prefix.

BQE Card Type Results

The first electronic card type to be reported on is from the 4.8 kilocycle power supply and has a serial number prefix of BQE. The total time on test plot for the first lifetime, shown in Figure 7, indicates the possibility of a Weibull distribution. The RDAAT statistical program gives the Weibull distribution hazard plot a .94 correlation coefficient and a shape parameter of 1.51. The RDAAT statistical program also indicates that a normal distribution may be the correct failure distribution and the normal distribution has a .97 correlation coefficient shown on its hazard plot. The Tiku goodness-of-fit test

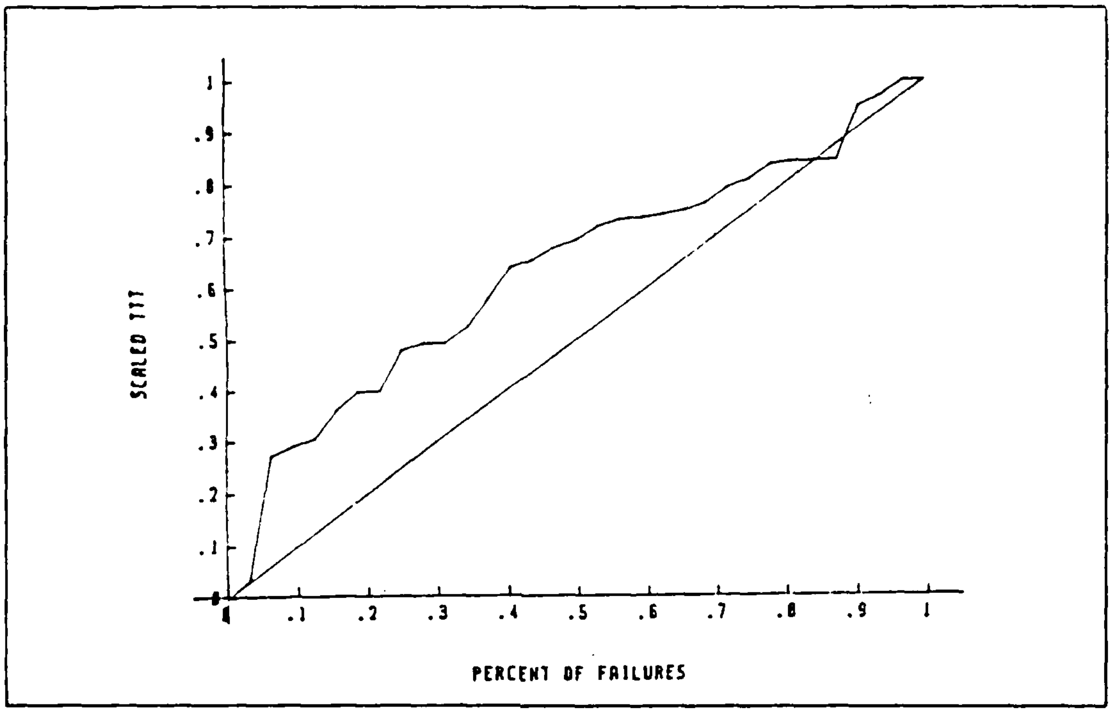

Figure 7. BQE 1st Lifetime Plot

for the normal distribution gives a .00003 chance of rejecting the null hypothesis when the normal distribution is, in fact, correct. These statistical tests give the indication of wearout existing in the first lifetime of this particular electronic card. The mean lifetime is 48623.69 hours for this electronic card.

The second lifetime total time on test plot for the BQE electronic card type, shown in Figure 8, indicates the possibility of an exponential distribution. The RDAAT hazard plot for the exponential distribution gives a .99 correlation coefficient and the Smith-Bain goodness-of-fit test indicates a .013 chance of rejecting the null

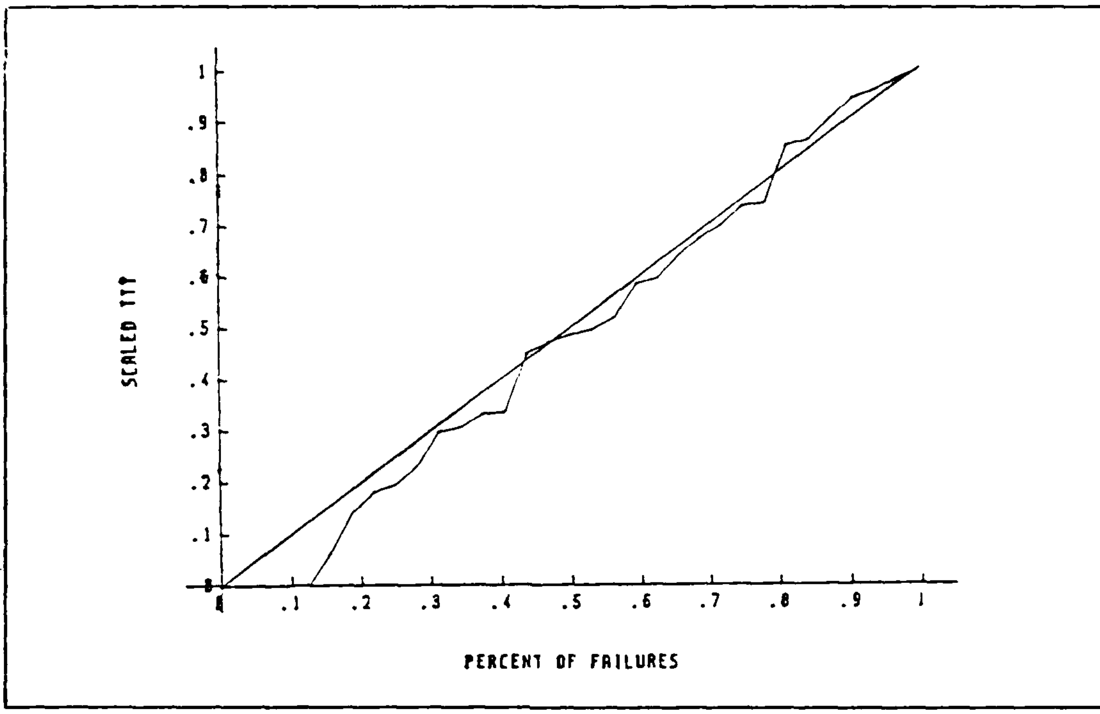

Figure 8. BQE 2nd Lifetime Plot

hypothesis when the exponential distribution is correct. The Tiku goodness-of-fit test indicates a .003 chance of rejecting the null hypothesis. The RDAAT statistical program also indicates that the Weibull distribution has a .95 correlation coefficient on its hazard plot with a .88 shape parameter. These statistical tests give the indication that this electronic card is in useful life. The mean lifetime is 10083.83 hours for this electronic card.

The third lifetime total time on test plot for the BQE electronic card type, shown in Figure 9, indicates the possibility of an exponential distribution. The RDAAT

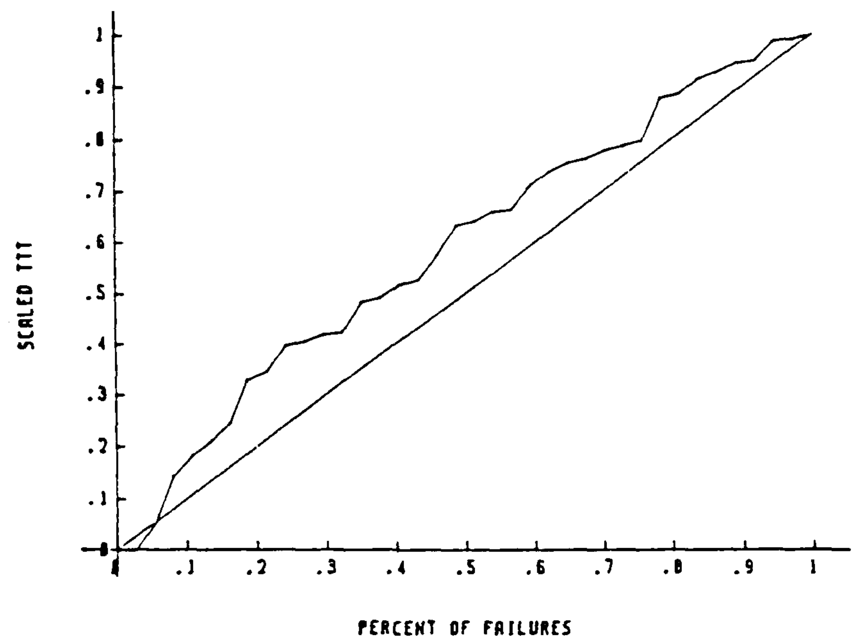

Figure 9. BQE 3rd Lifetime Plot

hazard plot for the exponential distribution gives a .98 correlation coefficient and the Tiku goodness-of-fit test indicates a .0005 chance of rejecting the null hypothesis when the exponential distribution is correct. The RDAAT statistical program also indicates that the Weibull failure distribution hazard plot has a correlation coefficient of 1.0 with a 1.31 shape parameter. These statistical tests give the indication that this electronic card is in useful life. The mean lifetime is 16100.42 hours for this electronic card. Table III summarizes the results for the BQE electronic card.

TABLE III

BQE Card Type Summary

Card Type	Lifetime	Mean Life (hours)	Tested Distribution	RDAAT Correlation Coefficient (Hazard Plot)	Goodness-of-fit Tiku	Smith-Bain
BQE	1	48623.69	Normal	.97	.00003	
			Weibull β=1.51	.94		
	2	10083.83	Exponential	.99	.003	.013
			Weibull β=.88	.95		.163
	3	16100.42	Exponential	.98	.0005	
			Weibull β=1.31	1.0		

BQQ Card Type Results

The second electronic card type to be reported on is from the 400 cycles per second fan power supply and has a serial number prefix of BQQ. The first lifetime total time on test plot, shown in Figure 10, indicates the possibility of an Weibull failure distribution. The RDAAT hazard plot for the Weibull distribution gives a .98 correlation coefficient and a shape parameter of 1.12. The RDAAT program also gives the normal failure distribution hazard plot a .98 correlation coefficient and the Tiku goodness-of-fit test indicates a .0284 chance of rejecting the null hypothesis when the normal failure distribution is correct. These statistical tests indicate that this electronic card

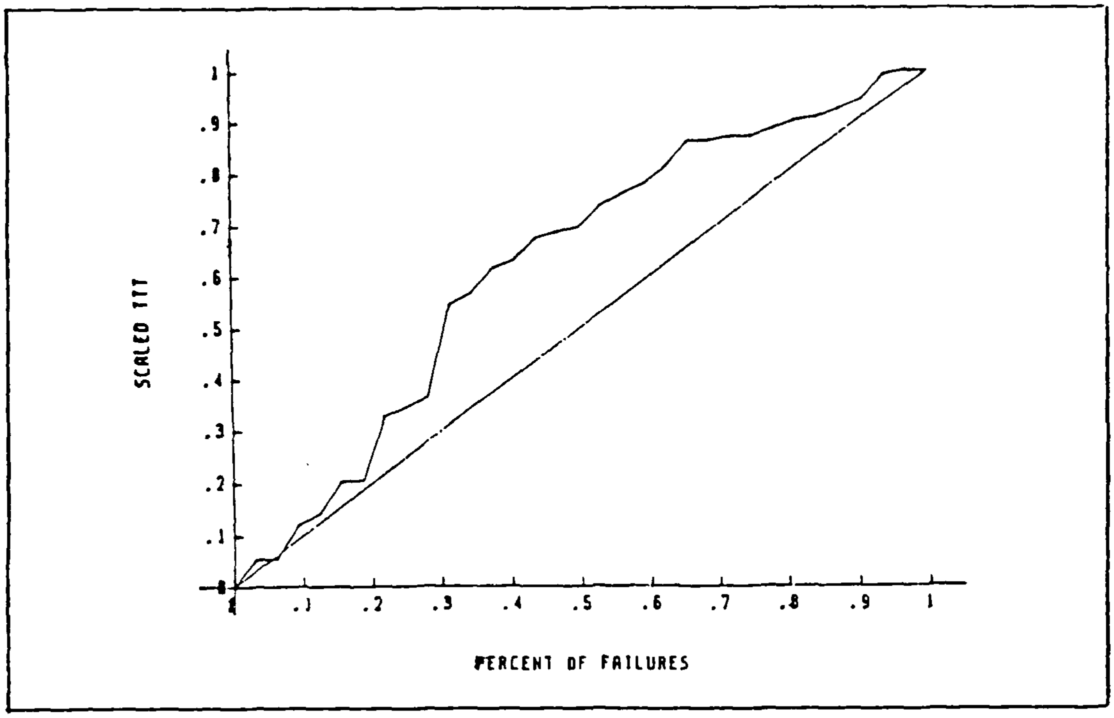

Figure 10. BQQ 1st Lifetime Plot

may be experiencing wearout. The mean lifetime is 46778.39 hours for this electronic card.

The second lifetime total on test plot for the BQQ electronic card, shown in Figure 11, indicates the possibility of an exponential failure distribution. The RDAAT program hazard plot for the exponential distribution gives a 1.0 correlation coefficient. The Smith-Bain goodness-of-fit test indicates a .01 chance of rejecting the null hypothesis and Tiku goodness-of-fit test indicates a .0000 chance of rejecting the null hypothesis when the exponential distribution is correct. The RDAAT statistical program also indicates the Weibull failure distribution

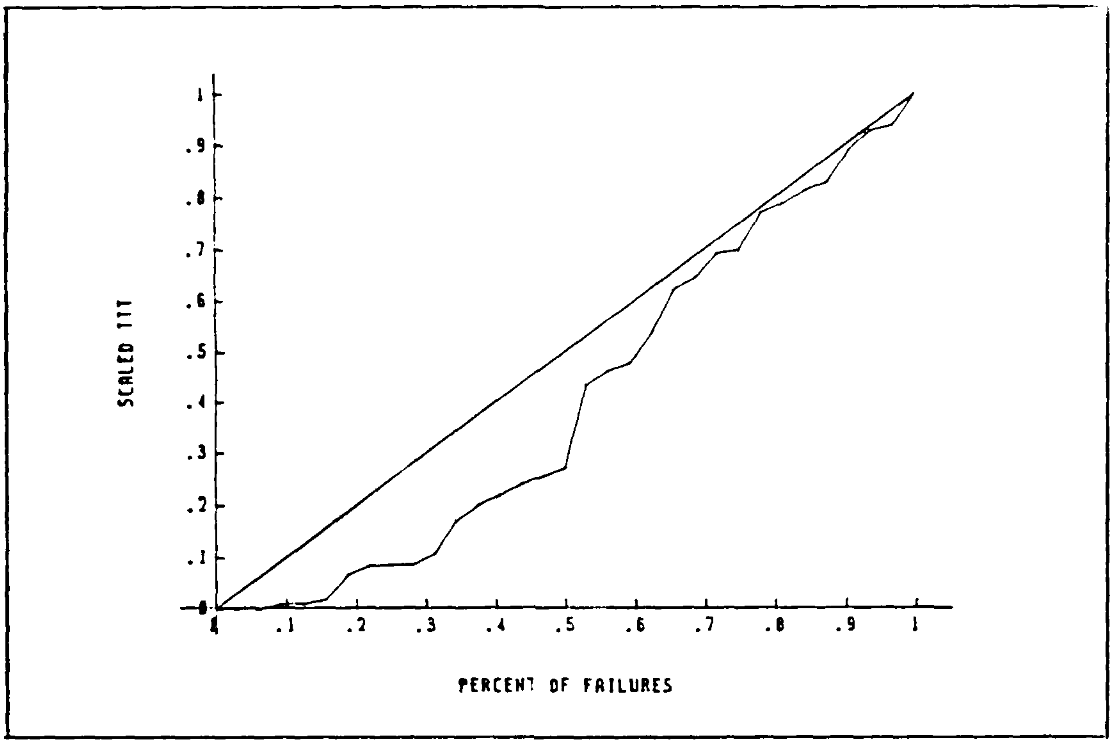

Figure 1]. BQQ 2nd Lifetime Plot

hazard plot has a correlation coefficient of .99 with a .70 shape parameter. The Smith Bain goodness-of-fit test indicates a .50 chance of rejecting the null hypothesis when the Weibull distribution is correct. These statistical tests give the indication that this electronic card is in useful life. The mean lifetime is 8175.70 hours for this electronic card.

The third lifetime total on test plot for the BQQ electronic card, shown in Figure 12, indicates the possibility of a Weibull failure distribution. The RDAAT program hazard plot for the Weibull distribution

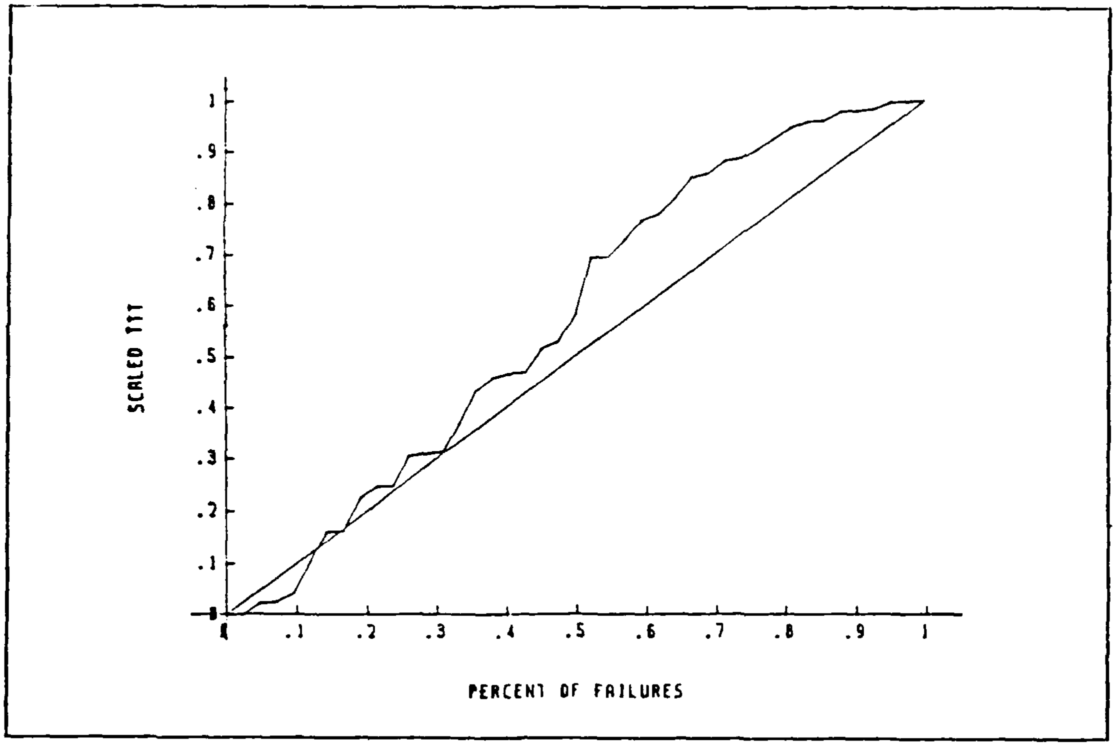

Figure 12. BQQ 3rd Lifetime Plot

gives a .98 correlation coefficient and a shape parameter of 1.04. The RDAAT program also gives the normal failure distribution a .98 correlation coefficient and the Tiku goodness-of-fit test indicates a .0000 chance of rejecting the null hypothesis when the normal distribution is correct. These statistical tests indicate that this electronic card may be experiencing wearout. The mean lifetime is 23216.02 hours for this electronic card. Table IV summarizes the results for the BQQ electronic card.

TABLE IV

BQQ Card Type Summary

Card Type	Lifetime	Mean Life (hours)	Tested Distribution	RDAAT Correlation Coefficient (Hazard Plot)	Goodness-of-fit Tiku	Goodness-of-fit Smith-Bain
BQQ	1	46778.38	Normal	.98	.0284	
			Weibull β=1.12	.98		
	2	8175.70	Exponential	1.0	.0000	.01
			Weibull β= .7	.99		.50
	3	23216.02	Normal	.98	.0000	
			Weibull β=1.04	.98		

BTJ Card Type Results

The third electronic card type to be reported on is from the missile guidance set control and has a serial number prefix of BTJ. The first lifetime total time on test plot for the BTJ electronic card, shown in Figure 13, indicates a normal failure distribution. The RDAAT program hazard plot for the normal distribution gives a .97 correlation coefficient. The Smith-Bain goodness-of-fit test indicates a .01 chance of rejecting the null hypothesis and the Tiku goodness-of-fit test indicates a .0000 chance of rejecting the null hypothesis when the normal distribution is correct. The RDAAT statistical program also indicates that the Weibull failure distribution hazard plot has a

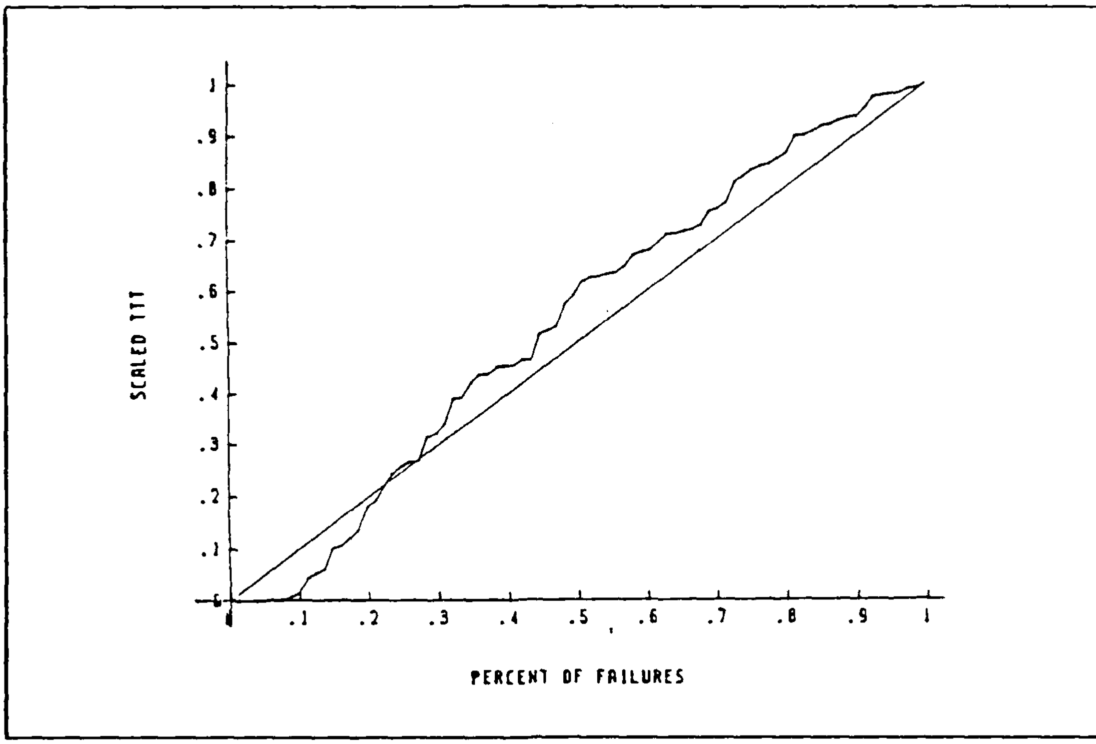

Figure 13. BTJ 1st Lifetime Plot

correlation coefficient of .96 and a .81 shape parameter. The Smith-Bain goodness-of-fit test indicates a .07 chance of rejecting the null hypothesis when the Weibull distribution is correct. These statistical tests indicate that this electronic card may be experiencing wearout. The mean lifetime is 34938.01 hours for this electronic card.

The second lifetime total time on test plot for the BTJ electronic card, shown in Figure 14, indicates an exponential failure distribution. The RDAAT program hazard plot gives a .99 correlation coefficient for the exponential distribution and the Tiku goodness-of-fit test

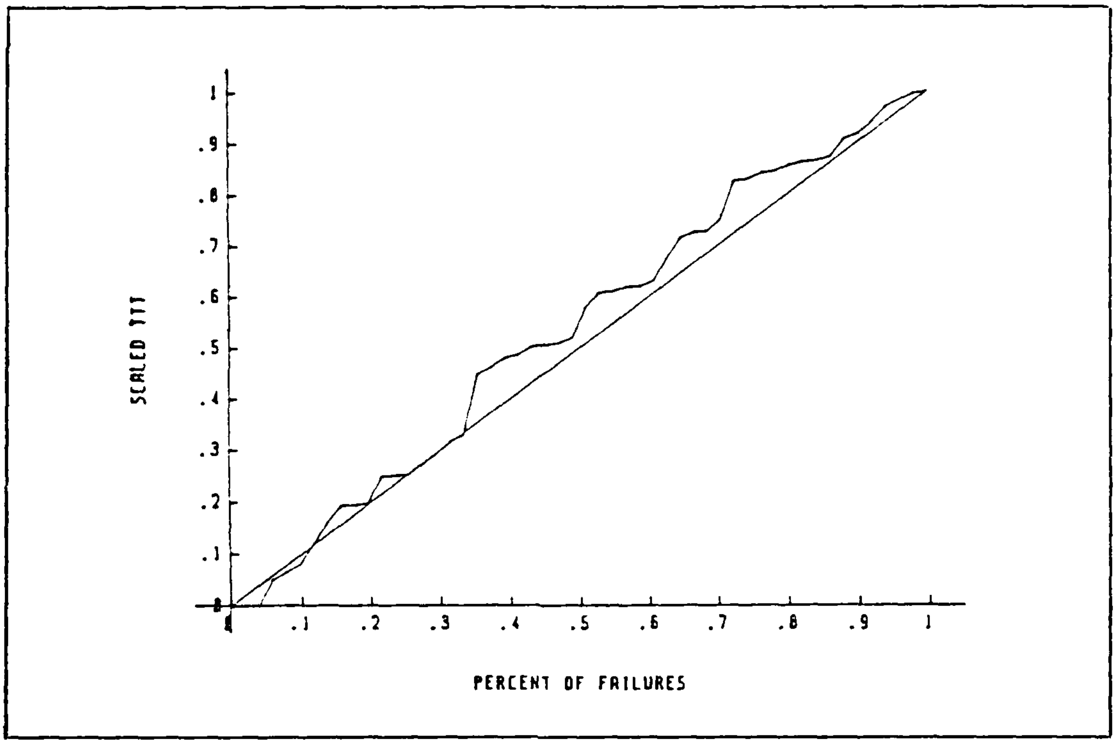

Figure 14. BTJ 2nd Lifetime Plot

indicates a .0000 chance of rejecting the null hypothesis when the exponential distribution is correct. The RDAAT program hazard plot for the Weibull failure distribution indicates a 1.0 correlation coefficient and a 1.16 shape parameter. These statistical tests indicate that this electronic card is in useful life. The mean lifetime is 14145.02 hours for this electronic card.

The third lifetime total time on test plot for the BTJ electronic card, shown in Figure 15, indicates an exponential failure distribution. The RDAAT program hazard plot gives a .96 correlation coefficient for the

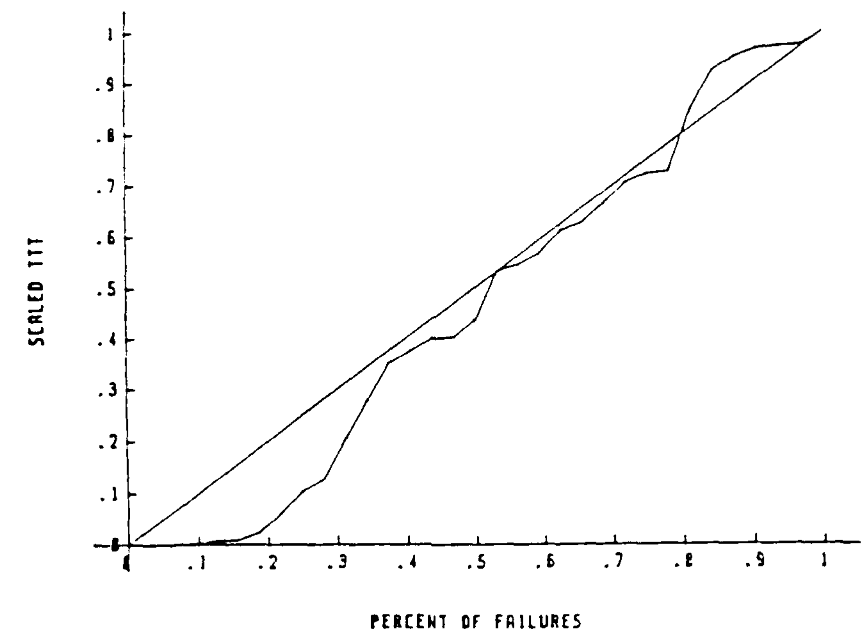

Figure 15. BTJ 3rd Lifetime Plot

exponential distribution and the Tiku goodness-of-fit test indicates a .0000 chance of rejecting the null hypothesis when the exponential distribution is correct. The RDAAT program hazard plot for the Weibull failure distribution indicates a .96 correlation coefficient and a .72 shape parameter. These statistical tests indicate that this electronic card is in useful life. The mean lifetime is 11762.23 hours for this electronic card. Table V summarizes the results for the BTJ electronic card.

TABLE V

BTJ Card Type Summary

Card Type	Lifetime	Mean Life (hours)	Tested Distribution	RDAAT Correlation Coefficient (Hazard Plot)	Goodness-of-fit Tiku	Goodness-of-fit Smith-Bain
BTJ	1	34938.01	Normal	.97	.0000	.01
			Weibull β=.81	.96		.07
	2	14145.02	Exponential	.99	.0000	
			Weibull β=1.16	1.0		
	3	11762.23	Exponential	.96	.0000	
			Weibull β=.72	.96		

SUQ Card Type Results

The next electronic card type to be reported on is from the x, y, or z ECA accelerometer and has a serial number prefix of SUQ. The first lifetime total time on test plot, shown in Figure 16, indicates an exponential failure distribution. The RDAAT program hazard plot gives a .72 correlation coefficient for the exponential distribution and the Tiku goodness-of-fit test indicates a .0948 chance of rejecting the null hypothesis when the exponential distribution is correct. The RDAAT program hazard plot gives a .92 correlation coefficient for the normal distribution and the Tiku goodness-of-fit test indicates a .0000 chance of rejecting the null hypothesis when the normal distribution is correct. These statistical

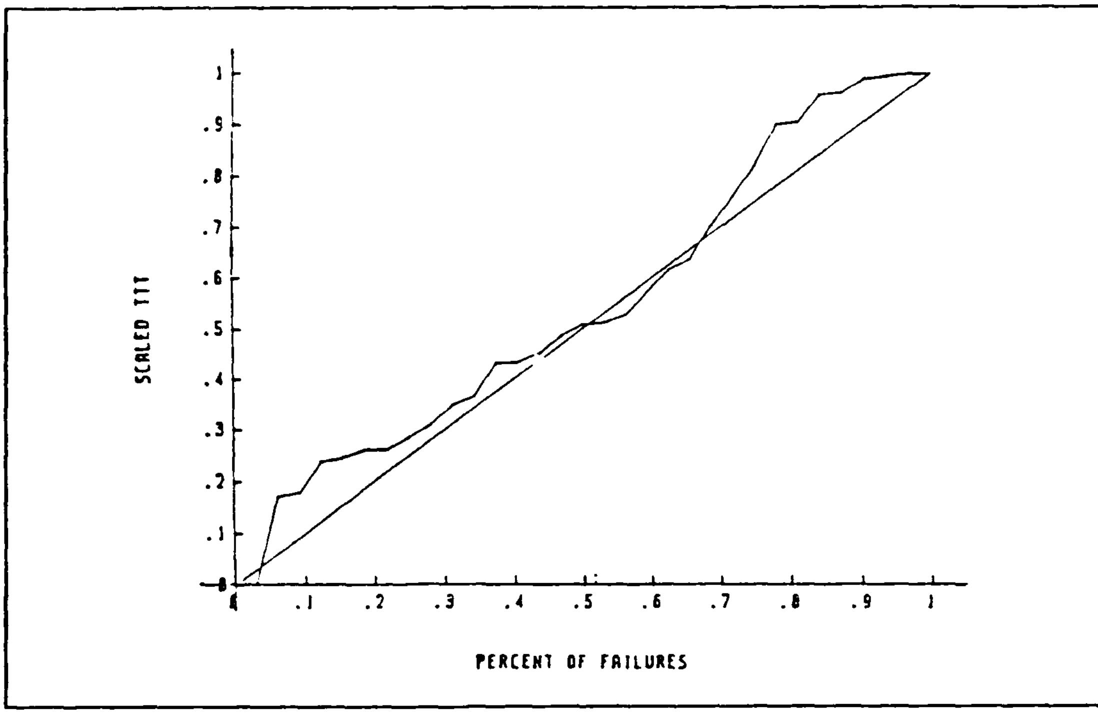

Figure 16. SUQ 1st Lifetime Plot

tests indicate that this electronic card may be experiencing wearout. The mean lifetime is 45472.72 hours for this electronic card.

The second lifetime total time on test plot for the SUQ electronic card, shown in Figure 17, indicates a normal failure distribution. The RDAAT program hazard plot gives a .99 correlation coefficient for the normal distribution. The Weibull distribution hazard plot as a .96 correlation coefficient with a shape parameter of 1.42. The Smith-Bain goodness-of-fit test indicates a .021 chance of rejecting the null hypothesis and the Tiku goodness-of-fit test indicates a .0024 chance of rejecting the null hypothesis

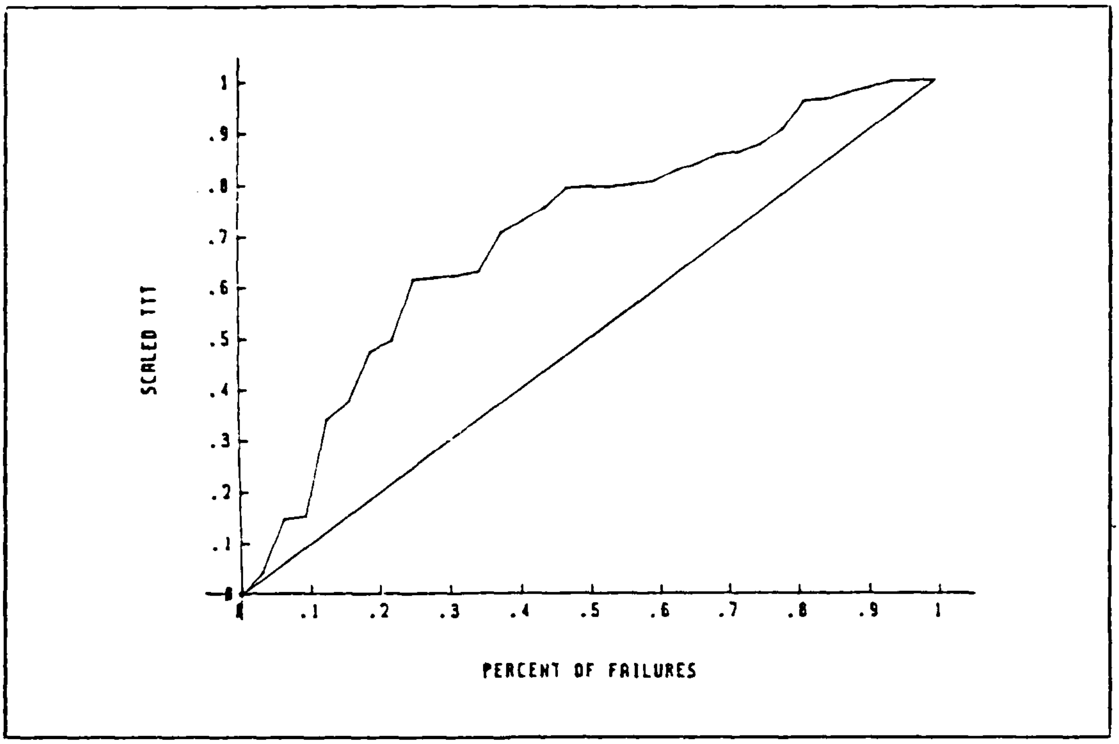

Figure 17. SUQ 2nd Lifetime Plot

for the normal distribution. The Smith-Bain test indicates a .31 chance of rejecting the null hypothesis for the Weibull distribution. These statistical tests indicate that this electronic card may be experiencing wearout. The mean lifetime is 41551.59 hours for this electronic card.

The third lifetime total time on test plot for the SUQ electronic card, shown in Figure 18, indicates a possible exponential failure distribution. However, the plot does give indications of early infant mortality. The RDAAT program hazard plot gives a .95 correlation

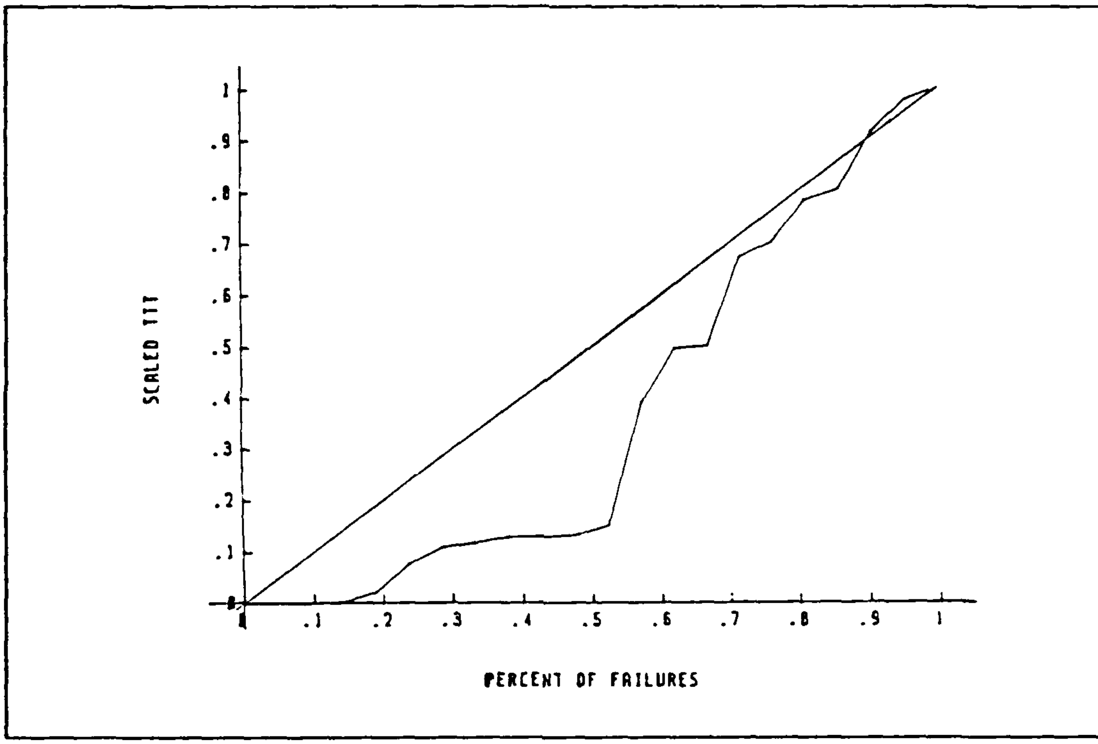

Figure 18. SUQ 3rd Lifetime Plot

coefficient for the exponential distribution and the Tiku goodness-of-fit test indicates a .0000 chance of rejecting the null hypothesis when the exponential distribution is correct. The RDAAT program also indicates that the Weibull failure distribution has a .96 correlation coefficient with a .68 shape parameter. These statistical tests indicate that this electronic card is in useful life. The mean lifetime is 11206.53 hours for this electronic card. Table VI summarizes the results for the SUQ electronic card.

TABLE VI

SUQ Card Type Summary

Card Type	Lifetime	Mean Life (hours)	Tested Distribution	RDAAT Correlation Coefficient (Hazard Plot)	Goodness-of-fit Tiku	Goodness-of-fit Smith-Bain
SUQ	1	45472.72	Exponential	.72	.0948	
			Normal	.92	.0000	
	2	41551.59	Normal	.99	.0024	.0210
			Weibull β=1.42	.96		.31
	3	11206.53	Exponential	.95	.0000	
			Weibull β=.68	.96		

SYL Card Type Results

The last electronic card type to be reported is from the Minuteman III stabilized platform and has a serial number prefix of SYL. The first lifetime total time on test plot, shown in Figure 19, indicates an exponential failure distribution. The RDAAT program hard plot gives a .97 correlation coefficient for the exponential distribution. The Smith-Bain goodness-of-fit test indicates a .01 chance of rejecting the null hypothesis and the Tiku goodness-of-fit indicates a .0000 chance of rejecting the null hypothesis when the exponential distribution is correct. The RDAAT program hazard plot for the Weibull failure distribution indicates a .99

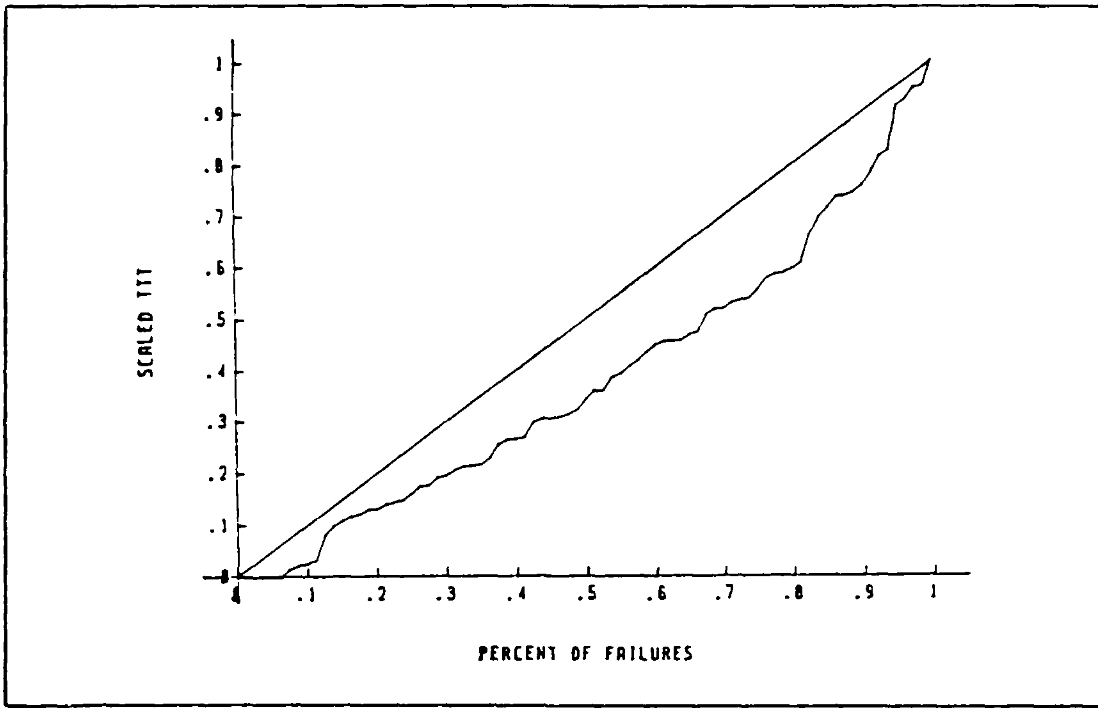

Figure 19. SYL 1st Lifetime Plot

correlation coefficient and a .99 shape parameter. The Smith-Bain goodness-of-fit test indicates a .195 chance of rejecting the null hypothesis when the Weibull distribution is correct. These statistical tests indicate that this electronic card is in useful life. The mean lifetime is 11359.13 hours for this electronic card.

The second lifetime total time on test plot for the SYL electronic card, shown in Figure 20, indicates an exponential failure distribution. The RDAAT program hazard plot gives a .98 correlation coefficient for the exponential distribution. The Smith-Bain goodness-of-fit test indicates a .01 chance of rejecting the null

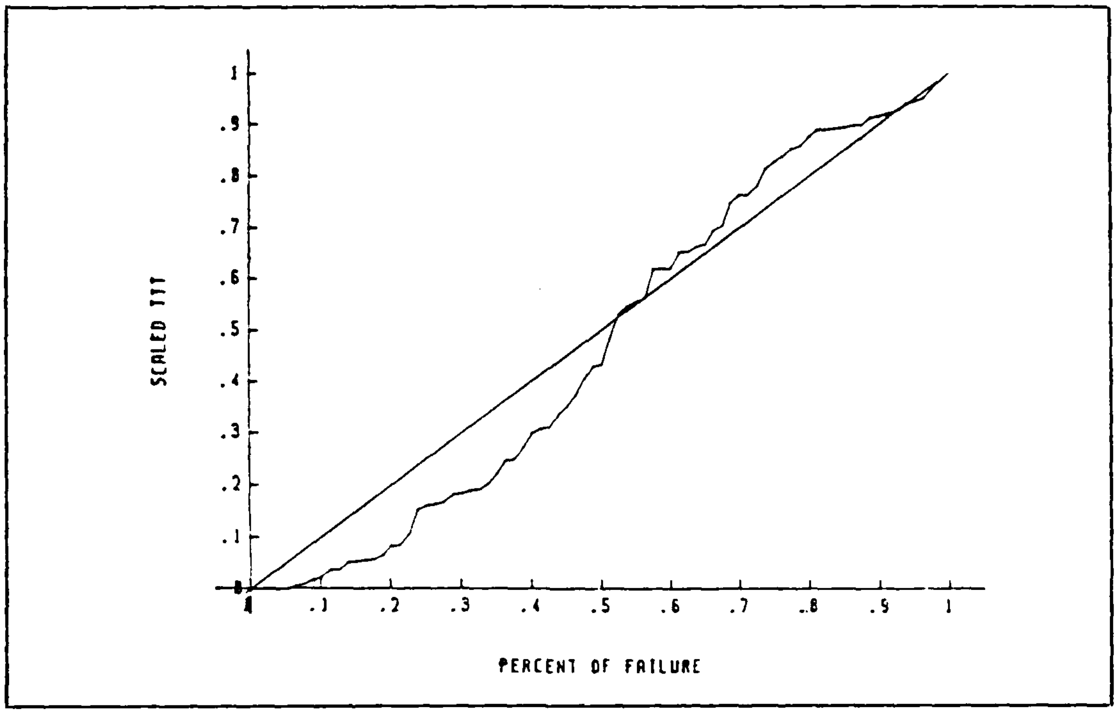

Figure 20. SYL 2nd Lifetime Plot

hypothesis and the Tiku goodness-of-fit indicates a .0000 chance of rejecting the null hypothesis when the exponential distribution is correct. The RDAAT program hazard plot for the Weibull failure distribution indicates a .99 correlation coefficient and a .84 shape parameter. The Smith-Bain goodness-of-fit test indicates a .50 chance of rejecting the null hypothesis when the Weibull distribution is correct. These statistical tests indicate that this electronic card is in useful life. The mean lifetime is 11476.12 hours for this electronic card.

The third lifetime total time on test plot for the SYL electronic card, shown in Figure 21, indicates an

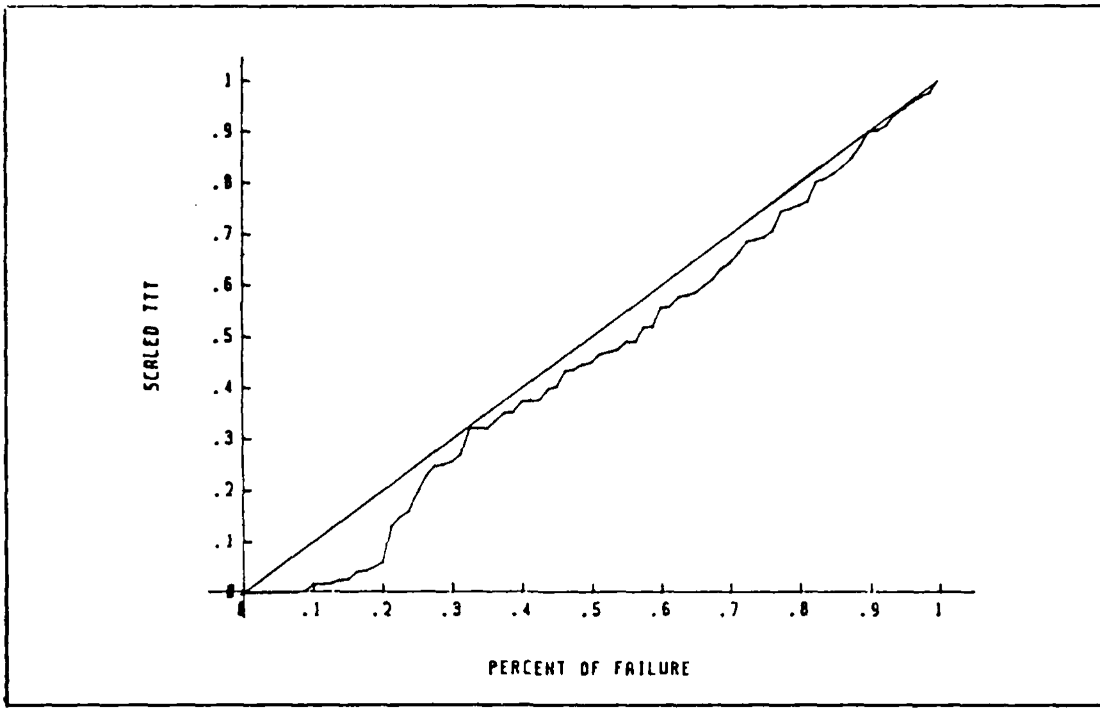

Figure 21. SYL 3rd Lifetime Plot

exponential failure distribution. The RDAAT program hazard plot gives a 1.0 correlation coefficient for the exponential distribution. The Smith-Bain goodness-of-fit test indicates a .01 chance of rejecting the null hypothesis and the Tiku goodness-of-fit indicates a .0000 chance of rejecting the null hypothesis when the exponential distribution is correct. The RDAAT program hazard plot for the Weibull failure distribution indicates a .98 correlation coefficient and a .76 shape parameter. The Smith-Bain goodness-of-fit test indicates a .405 chance of rejecting the null hypothesis when the Weibull distribution is correct. These statistical tests indicate

that this electronic card is in useful life. The mean lifetime is 12111.20 hours for this electronic card. Table VII summarizes the results for the SYL electronic card.

TABLE VII

SYL Card Type Summary

Card Type	Lifetime	Mean Life (hours)	Tested Distribution	RDAAT Correlation Coefficient (Hazard Plot)	Goodness-of-fit Tiku	Goodness-of-fit Smith-Bain
SYL	1	11359.13	Exponential	.97	.0000	.01
			Weibull β=.99	.99		.195
	2	11476.12	Exponential	.98	.0000	.01
			Weibull β=.84	.99		.50
	3	12111.20	Exponential	1.0	.0000	.01
			Weibull	.98		.405

<u>Summary</u>

Use of the total time on test graphical procedure and the RDAAT statistical program has allowed us to determine the most probable failure distributions, hazard functions, and lifetime patterns for the electronic cards examined in this research. Use of these procedures has also allowed us to answer the questions that prompted this research effort:

1. Does infant mortality exist in electronic cards of the Minuteman III guidance system?

2. Are electronic cards of the Minuteman III guidance system wearing out?

3. Are the electronic cards in the Minuteman III guidance system in useful life?

The next portion of the research effort will include conclusions, recommendations to management, and other possible uses of these findings.

V. Conclusions and Recommendations

This chapter will present our conclusions based on our findings and recommendations for future study and research. The goal of this research was to describe the failure distributions of selected electronic cards from the Minuteman III guidance system and to detect what failure pattern existed in those cards.

Research Objectives

The objectives of this research were:

1. To describe the failure distributions of selected electronic cards in the Minuteman III guidance system.

2. To determine if the corresponding hazard function demonstrated infant mortality, wearout, or useful life.

3. To suggest management strategies to deal with infant mortality or wearout.

This research was also accomplished because the Total Time on Test graphical technique had not been used to determine failure distributions for Minuteman failure data.

Conclusions

The BQE electronic card had a first mean lifetime of 48623 hours, a second mean lifetime of 10083 hours, and a third mean lifetime of 16100 hours. The first lifetime failure distribution was Weibull with a shape parameter of 1.51, which would indicate wearout. The two remaining

lifetimes examined for this card indicated exponential failure distributions. From this failure distribution, we can conclude that the card was in useful life. Noting the significant difference in the mean lifetimes on this card, we can conclude that this card was not repaired to as good as new condition.

The BQQ electronic card had a first mean lifetime of 46778 hours, a second mean lifetime of 8175 hours, and a third mean lifetime of 23216 hours. The first lifetime failure distribution was Weibull with a shape parameter of 1.12. The third lifetime for this card also indicated a Weibull distribution and had a shape parameter of 1.04. Recall that a Weibull distribution with a shape parameter of 1 is the exponential distribution. Both of these lifetimes have shape parameters that are very close to 1, indicating that these lifetimes may not be wearing out, but rather are in useful life. The second mean lifetime of this card was significantly less than either of the other two. We cannot conclude why this occurred; however, it is interesting to note that the third mean lifetime of this card increased significantly over the second. This card type also has significant differences between the mean lifetimes and because of that we can conclude that this card was not repaired to as good as new condition.

The BTJ electronic card had a first mean lifetime of 34938 hours, a second mean lifetime of 14145 hours, and a

third mean lifetime of 11762 hours. The first lifetime had a normal failure distribution and the second and third lifetimes had exponential failure distributions. The normal distribution gives the indication that the first lifetime may have been showing signs of wearout. The second and third lifetimes were both in useful life. However, there is also a significant difference in the mean lifetimes for this card type. The largest difference is between the first and second lifetime. The second mean lifetime is less than 50 percent of the first mean lifetime. Again, we can conclude that this card was not repaired to as good as new condition.

The SUQ electronic card had a first mean lifetime of 45472 hours, a second mean lifetime of 41551 hours, and a third mean lifetime of 11206 hours. The first lifetime failure distribution was normal, indicating possible wearout. The second lifetime also indicated a normal failure distribution or a Weibull failure distribution with a 1.42 shape parameter, which would also indicate possible wearout. The third lifetime had an exponential failure distribution and would indicate useful life. Note that the first two mean lifetimes are quite high and that the third lifetime is significantly less. This would tend to indicate that during the second repair cycle of this card, it was not repaired to as good as new condition.

The SYL electronic card was the only card selected from the stabilized platform of the guidance system. It was selected because it had the most lifetimes of any of the cards on which we had data. The first mean lifetime of the SYL electronic card was 11359 hours, the second mean lifetime was 11476 hours, and the third mean lifetime was 12111 hours. All three lifetimes had exponential failure distributions, indicating useful life, and there were no significant differences between the lengths of the mean lifetimes.

Recommendations for Further Research

Based on the findings of this research, three areas are recommended for further research.

1. Further research needs to be accomplished to determine if the differences in the mean lifetimes within a specific card type is significant.

2. Determine why only one card type (SYL) has a significant failure history beyond three lifetimes and, since this card is from the stabilized platform, attempt to determine if the stabilized platform is a limiting factor in guidance system reliability.

3. Further use of the Total Time on Test performance is necessary to validate its applicability to this type of data.

Summary

Through the use of the Total Time on Test graphical technique and the RDAAT statistical package, we have described the failure distributions and hazard functions for five selected electronic cards. Recall that the failure distributions and hazard functions described are for the first three lifetimes of these selected electronic cards.

Nine of the fifteen lifetimes examined indicated that the exponential distribution correctly identified the failure pattern of those electronic cards. It can be concluded that the lifetimes that show an exponential failure distribution have a constant failure rate and are in useful life. The other six lifetimes were identified as either a Weibull with a shape parameter greater than one, or a normal distribution. It can be concluded that the lifetimes that show a normal failure distribution or a Weibull failure distribution, with a shape parameter greater than one, are indicating signs of wearout. However, two of the lifetimes that indicated a Weibull distribution had shape parameters very close to one. This occurred in one type of electronic card (BQQ) and could lead to the conclusion that these lifetimes are, in fact, failing exponentially and are in useful life, not wearout. The other four lifetimes that indicate wearout failure distributions have mean lifetimes, derived from the RDAAT

statistical package, that exceed 34900 hours. Recall from Chapter I that the system mean time between failure is approximately 10000 hours. With this in mind, a card with wearout characteristics and a mean lifetime of 34900 hours may not require any management action. Data was provided for 44 electronic cards; however, the five selected for this research were the only cards that had significant numbers of failures beyond two lifetimes. The system has been in constant operation since the early 1970s and, as reported in Chapter I, is improving its reliability performance with age. Perhaps further research will indicate possible trends that require management action such as preventive maintenance.

Appendix A. Original Data and Format

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NBKM0989S01083G7073117504E0346640000000000034664050020050002
003466405002003466405002003466405002000000      00590500201

NBKM0993S05296D10830098311E05848700000000000584870843960843 9
605848708439605848708439605848708439600000      01030843961
```

Column	Element
1	Filler
2	Item Serial Number
9-13	System Serial Number
14-16	Site
17	Operational Mode
18-21	Install Date (YYMM)
22-25	Remove Date
26	Filler
27-32	Operational Hours (Cumulative)
33-34	Cumulative Primary Failure Count
35-36	Filler
37-38	Cumulative Verified Failures
39-40	Filler
41-42	Cumulative Total Removals
43-60	Filler
61-66	Hours Since Last Verified Failure
67-84	Filler
85-90	Hours Since Last Removal
91-96	Filler
97	Primary Failure Indicator (0 or 1)
98	Filler
99	Verified Failure Indicator (0 or 1)
100	Filler
101	Removal Indicator (0 or 1)
102-104	Failure Diagnostic Code
105-116	Filler

Appendix B. Fortran Programs

This program was used to read the original data file and selected all electronic cards that had a failure indicated in columns 37-38.

```
      CHARACTER*3,CARD
      INTEGER SN,FAIL,HOURS,CHGHR
      OPEN (UNIT=8,FILE='INPUTFILENAME')
      OPEN (UNIT-2,FILE-'OUTPUTFILENAME')
 99   READ (8,100) CARD,SN,HOURS,FAIL,CHGHR
      I=I+1
      IF (FAIL .GT. 0) WRITE (2,110)CARD,SN,HOURS,FAIL,CHGHR
      IF (I .EQ. 320000) GOTO 999
      GOTO 99
100   FORMAT (2X,A3,I4,17X,I6,4X,82,23X,I6,50X
110   FORMAT (5X,A3,3X,I4,I6,3X,I2,3X,I6)
999   STOP
      END
```

Variations of this program were used to sort the failures selected by the program above into individual data files. The only changes required were to the input filename (line 3), the output filename (line 4), the 'if' statement specifying what was being selected (line 7), and the size of the file being read (line 8).

```
      CHARACTERS*3,CARD,BQE,BQQ,BTJ,SUQ,SYL
      INTEGER SN,FAIL,HOURS,CHGHR
      OPEN (UNIT=8, FILE='INPUTFILENAME')
      OPEN (UNIT=2, FILE='OUTFUTFILENAME')
 99   READ 98,2100) CARD,SN,HOURS,FAIL,CHGHR
      I=I+1
      IF (CARD.EQ.BQE)WRITE(2,110)CARD,SN,HOURS,FAIL,CHGHR
      IF (I. EQ. 10000) GOTO 999
      GOTO 99
100   FORMAT (5X,A3,3X,I4,3X,I6,3X,I2,3X,I6)
110   FORMAT (5X,A3,3X,I4,3X,I6,3X,I2,3X,I6)
999   STOP
      END
```

Appendix C. Table of Random Units

PROBABILITY AND STATISTICS

Table of Random Units

A TABLE OF 14,000 RANDOM UNITS (Continued)

Line/Col.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
51	10408	81899	04153	53381	79401	21438	83035	92350	36693	31238	59649	91754	72772	02338
52	18629	81953	05520	91962	04739	13092	97662	24822	94730	06496	35090	04822	86772	98289
53	73115	35101	47498	87637	99016	71060	88824	71013	18735	20286	23153	72924	35165	43040
54	57491	16703	23167	49323	45021	33132	12544	41035	80780	45393	44812	12515	98931	91202
55	30405	83946	23792	14422	15059	45799	22716	19792	09983	74353	68668	30429	70735	25499
56	16631	35006	85900	98275	32388	52390	16815	69298	82732	38480	73817	32523	41961	44437
57	96773	20206	42559	78985	05300	22164	24369	54224	35083	19687	11052	91491	60383	19746
58	38935	64202	14349	82674	66523	44133	00697	35552	35970	19124	63318	29686	03387	59846
59	31624	76384	17403	53363	44167	64486	64758	75366	76554	31601	12614	33072	60332	92325
60	78919	19474	23632	27889	47914	02584	37680	20801	72152	39339	34806	08930	85001	87820
61	03931	33309	57047	74211	63445	17361	62825	39908	05607	91284	68833	25570	38818	46920
62	74426	33278	43972	10119	89917	15665	52872	73823	73144	88662	88970	74492	51805	99378
63	09066	00903	20795	95452	92648	45454	09552	88815	16553	51125	79375	97596	16296	66092
64	42238	12426	87025	14267	20979	04508	64535	31355	86064	29472	47689	05974	52468	16834
65	16153	08002	26504	41744	81959	65642	74240	56302	00033	67107	77510	70625	28725	34191
66	21457	40742	29820	96783	29400	21840	15035	34537	33310	06116	95240	15957	16572	06004
67	21581	57802	02050	89728	17937	37621	47075	42080	97403	48626	68995	43805	33386	21597
68	55612	78095	83197	33732	05810	24813	86902	60397	16489	03264	88525	42786	05269	92532
69	44657	66999	99324	51281	84463	60563	79312	93454	68876	25471	93911	25650	12682	73572
70	91340	84979	46949	81973	37949	61023	43997	15263	80644	43942	89203	71795	99533	50501
71	91227	21199	31935	27022	84067	05462	35216	14486	29891	68607	41867	14951	91696	85065
72	50001	38140	66321	19924	72163	09538	12151	06878	91903	18749	34405	56087	82790	70925
73	65390	05224	72958	28609	81406	39147	25549	48542	42627	45233	57202	94617	23772	07896
74	27504	96131	83944	41575	10573	08619	64482	73923	36152	05184	94142	25299	84387	34925
75	37169	94851	39117	89632	00959	16487	65536	49071	39782	17095	02330	74301	00275	48280
76	11508	70225	51111	38351	19444	66499	71945	05422	13442	78675	84081	66938	93654	59894
77	37440	30362	06694	54690	04052	53115	62757	95348	78662	11163	81651	50245	34971	52924
78	46515	70331	85922	38329	57015	15765	97161	17869	45349	61796	66345	81073	49106	79860
79	30986	81223	42416	58353	21532	30502	32305	86482	05174	07901	54339	58861	74818	46942
80	63798	64995	46583	09765	44160	78128	83991	42865	92520	83531	80377	35909	81250	54238
81	82486	84846	99254	67632	43218	50076	21361	64816	51202	88124	41870	52689	51275	83556
82	21885	32906	92431	09060	64297	51674	64126	62570	26123	05155	59194	52799	28225	85762
83	60336	98782	07408	53458	13564	59089	26445	29789	85205	41001	12535	12133	14645	23541
84	43937	46891	24010	25560	86355	33941	25786	54990	71899	15475	95434	98227	21824	19585
85	97656	63175	89303	16275	07100	92063	21942	18611	47348	20203	18534	03862	78095	50136
86	03299	01221	05418	38982	55758	92237	26759	86367	21216	98442	08303	56613	91511	75928
87	79626	00486	03574	17668	07785	76020	79924	25651	83325	88428	85076	72811	22717	50585
88	85636	68335	47539	03129	65651	11977	02510	26113	99447	68645	34327	15152	55230	93448
89	18039	14367	61337	06177	12143	46609	32989	74014	64708	00533	35398	58408	13261	47908
90	08362	15656	60627	36478	65648	16764	53412	09013	07832	41574	17639	82163	60859	75567
91	79556	29068	04142	16268	15387	12856	66227	38358	22478	73373	88732	09443	82558	05250
92	92608	82674	27072	32534	17075	27698	98204	63863	11951	34648	88022	56148	34925	57031
93	23982	25835	40055	67006	12293	02753	14827	22235	35071	99704	37543	11601	35503	85171
94	09915	96306	05908	97901	28395	14186	00821	80703	70426	75647	76310	88717	37890	40129
95	50937	33300	26695	62247	69927	76123	50842	43834	86654	70959	79725	93872	28117	19233
96	42488	78077	69882	61657	34136	79180	97526	43092	04098	73571	80799	76536	71255	64239
97	46764	86273	63003	93017	31204	36692	40202	35275	57306	55543	53203	18098	47625	88684
98	03237	45430	55417	63282	90816	17349	88298	90183	36600	78406	06216	95787	42579	90730
99	86591	81482	52667	61583	14972	90053	89534	76036	49199	43716	97548	04379	46370	28672
100	38534	01715	94964	87288	65680	13772	39560	12918	86537	62738	19636	51132	25739	56947

(8:557)

Appendix D. Total Time on Test Program

```
10 'TOTAL TIME ON TEST PLOTTING TECHNIQUE
20 'WRITTEN BY CAPT WILLLIAM RIMPO, MAJ JOHN KUTZKE, AND LTCOL CARLOS TALBOTT
30 '
40 CLS:PRINT"TOTAL TIME ON TEST ANALYSIS OF FAILURE DATA"
50 PRINT
60 PRINT "THIS PROGRAM CALCULATES A TOTAL TIME ON TEST STATISTIC FOR FAILURE
70 PRINT "DATA FROM A COMPLETE LIFE TEST, AS WELL AS FROM FIELD FAILURE DATA
80 PRINT "CONTAINING CENSORED UNITS.
90 PRINT
100 DIM A(500),TTT(500),STTT(500),B(500,21),C(500),LAST(500)
110 DEFINT G-J
120 '
130 PRINT "WELCOME TO TOTAL TIME ON TEST.
140 PRINT "IF YOU WOULD LIKE TO USE AN EXISTING DATABASE ON FILE, PRESS F.
150 PRINT "IF YOU WOULD LIKE TO CREATE A NEW DATA FILE, PRESS C.
160 PRINT "IF YOU WOULD LIKE TO ENTER DATA MANUALLY, PRESS M.
170 CLOSE #7
180 LET K=0
190 B$=INPUT$(1)
200   IF B$="F" THEN 230
210   IF B$="C" THEN 380
220   IF B$="M" THEN 530
230 I=1
240 '
250 'ARRAY C(I) STORES FAILURE INDICATOR: 1 FOR FAILURE, 0 FOR CENSORED DATA
260 'ARRAY A(I) STORES LIFETIMES
270 '
280 '
290 LINE INPUT "MY DATA FILE IS:  ";E$
300 I=1
310 OPEN "I",#1, E$
320 IF EOF (1) THEN 660
330 INPUT #1,C(I),A(I):PRINT C(I),A(I)
340 IF C(I)=1 THEN K=K+1
350 LET I=I+1
360 GOTO 320
370 PRINT
380 CLS:PRINT "YOU ARE ABOUT TO CREATE A DATAFILE WHICH YOU WILL NAME.
390 PRINT "PLEASE REMEMBER YOU FILE NAME.  AFTER THE LAST INPUT TYPE -1
400 PRINT "TO END DATA ENTRY.
410 '
420 LINE INPUT"MY DATA FILE NAME WILL BE:";  E$
430 '
440 OPEN "O",#7,E$
450 INPUT "ENTER 1 FOR FAILED UNIT, 0 FOR UNFAILED/WITHDRAWN UNIT";C(I)
460 INPUT "ENTER FAILURE/CENSORED TIME.";A(I)
470 IF C(I)=-1 THEN 500
480 WRITE#7,C(I),A(I)
490 PRINT: GOTO 450
500 CLOSE #7
510 GOTO 300
520 '
530 CLS:INPUT"ENTER NUMBER OF LIFETIMES";N
540 PRINT N
550 FOR I=1 TO N
560 INPUT "ENTER 1 FOR FAILED UNIT, 0 FOR UNFAILED/WITHDRAWN UNIT";C(I)
570 PRINT C(I)
580 INPUT"ENTER LIFETIME";A(I)
590 PRINT A(I)
600 '
610 'K COUNTS THE NUMBER OF FAILURES
620 '
630 IF C(I)=1 THEN K=K+1
640 PRINT K
650 NEXT I
660 N=I-1
670 REALN!=N
680 '
690 'OPENS FILES TO STORE TTT STATISTICS
700 '
```

```
710 OPEN "O",8,"AGE1.DAT"
720 '
730 'HERE THE ARRAY A(I) RECORDS UNORDERED LIFETIMES
740 'NOW SORT A(I) TO ORDERED LIFETIMES
750 '
760 LET F=0
770 FOR I=1 TO N-1
780 IF A(I)<=A(I+1) THEN GOTO 830
790 LET TEMP=A(I)
795 LET TEMPC=C(I)
800 LET A(I)=A(I+1)
805 LET C(I)=C(I+1)
810 LET A(I+1)=TEMP
815 LET C(I+1)=TEMPC
820 LET F=1
830 NEXT I
840 '
850 'IF F=1 THEN ORDER ISN'T PERFECT YET
860 '
870 IF F=1 GOTO 760
880 LINE INPUT "MY ORDERED DATA FILE IS:"; F$
890 OPEN "O",#5, F$
900 PRINT,"THE SET OF ORDERED LIFETIMES IS:"
910 FOR I=1 TO N
920 PRINT, I, "     "C(I),A(I)
930 WRITE #5,C(I),A(I)
940 NEXT I
950 CLOSE #5
960 '
970 'TOTAL TIME ON TEST SUBROUTINE
980 '
990 LET G=0
1000 FOR J=1 TO N
1010 IF C(J)=1 THEN G=G+1
1020 IF J=1 THEN TTT(J)=N*A(J)
1030 IF J=1 GOTO  1050
1040 LET TTT(J)=TTT(J-1)+(N-J+1)*(A(J)-A(J-1))
1050 IF C(J)=1 THEN TEMP=TTT(J)
1060 LET LAST(G)=TEMP
1070 NEXT J
1080 '
1090 'SCALED TTT SUBROUTINE
1100 'CALCULATES A SCALED TTT FOR FAILURES ONLY.
1110 '
1120 FOR I=1 TO G
1130 '
1140 STTT(I)=LAST(I)/LAST(G)
1150 IF I=G THEN PRINT#8,0;0
1160 IF I=G THEN PRINT#8,1;1
1170 IF I=G THEN PRINT#8,0;0
1180 NEXT I
1190 PRINT
1200 PRINT "                SCALED TTT      VS      PERCENT FAILURES
1210 FOR F=1 TO K
1220 PRINT#8,STTT(F);F/K
1230 PRINT, STTT(F),"",F/K
1240 NEXT F
1250 '
1260 END
```

Appendix E. GRAFTALK Command Structure

1. . (GRAFTALK PROMPT)
2. . TITLE (OPTIONAL, NAMES YOUR GRAPH. UNDERLINE THE SPACE BETWEEN THE WORDS, AFTER THE FIRST WORD OF THE TITLE) <RETURN>
3. .X NAME (OPTIONAL, NAMES THE X-AXIS. UNDERLINE THE SPACE BETWEEN THE WORDS, AFTER THE FIRST WORD OF THE TITLE) <RETURN>
4. .Y NAME (OPTIONAL, NAMES THE Y-AXIS. UNDERLINE THE SPACE BETWEEN THE WORDS, AFTER THE FIRST WORD OF THE TITLE) <RETURN>
5. .X INTERVAL (OPTIONAL, DIVIDES THE X-AXIS AS YOU DECIDE. 20 IS A GOOD NUMBER <RETURN>
6. .Y RANGE -1 4 (OPTIONAL. SETS THE LOWER AND UPPER VALUES FOR THE Y AXIS DISPLAY. THESE VALUES DEPEND ON EACH OUTPUT. -1 AND 4 ARE FOR SAMPLE PROBLEM.)<RETURN>
7. .X RANGE -1 4 (OPTIONAL. SETS THE LOWER AND UPPER VALUES FOR THE Y AXIS DISPLAY. THESE VALUES DEPEND ON EACH OUTPUT. -1 AND 4 ARE FOR SAMPLE PROBLEM.)<RETURN>
8. .X AXIS POSITION 0 (THE X AXIS WILL BE PERPENDICULAR TO THE Y AXIS AT THE 0 POSITION ON THE Y AXIS) <RETURN>
9. .Y AXIS POSITION 0 (THE X AXIS WILL BE PERPENDICULAR TO THE Y AXIS AT THE 0 POSITION ON THE Y AXIS) <RETURN>
10. .DATAFILE BLOCK1.DAT (YOU ARE BRINGING THE DATAFILE YOU CREATED IN SCREEN INTO GRAFTALK) <RETURN>
11. .VIEW (OPTIONAL, ALLOWS YOU TO SEE AND ALTER, IF DESIRED, DATA FILE. TO EXIT VIEW, HIT CNTRL AND G AT THE SAME TIME.
12. .PLOT C1 VS C2 (YOU WILL PLOT A CHART USING COLUMN 1 AND COLUMN 2 OF YOUR DATA FILE) <RETURN>
13. .DATAFILE BLOCK2.DAT (NOW, YOU ARE BRINGING THE SECOND DATA FILE YOU CREATED IN SCREEN INTO GRAFTALK. THIS NEW DATAFILE WILL REPLACE THE OLD ONE) <RETURN>
14. .PLOT C1 VS C2 (THIS SECOND PLOT WILL OVERLAY THE FIRST USING THE SAME CHART VALUES) <RETURN>
15. .EXIT (TO EXIT GRAFTALK AND RETURN TO OPERATING SYSTEM) NOTE: YOU CAN OUTPUT THIS TO THE PRINTER BY TYPING DUMP <RETURN> TO EXIT GRAFTALK TYPE EXIT <RETURN>

Bibliography

1. Armstadter, Bertram L. Reliability Mathematics: Fundamentals, Practices, Procedures. New York: McGraw Hill, Inc., 1971.

2. Barlow, Richard E. "Analysis of Retrospective Failure Data Using Computer Graphics," Proceedings of the 1978 Annual Reliability and Maintainability Symposium. IEEE Press, Inc., 1978.

3. Barlow, Richard E. "Geometry of the Total Time on Test Transform," Naval Research Logistics Quarterly, 26: 393-402 (Fall 1979).

4. Barlow, Richard E. and Raphael Campo. "Total Time on Test Processes and Applications to Failure Data Analysis," Reliability and Fault Tree Analysis, Edited by R. E. Barlow, J. Fussel, and N. D. Singpurwalla. Philadelphia: SIAM, 451-481, 1975.

5. Barlow, Richard E. and Frank Proschan. Mathematical Theory of Reliability. New York: John Wiley and Sons, Inc., 1965.

6. Bazovsky, Igor. Reliability Theory and Practice. Englewood Cliffs NJ: Prentice-Hall, Inc., 1962.

7. Bergman, Bjorn. "Some Graphical Methods for Maintenance Planning," Proceedings of the 1977 Annual Reliability and Maintainability Symposium. IEEE Press, New York, 1978.

8. Beyer, William H. CRC Standard Mathematical Tables. Boca Raton FL: CRC Press, Inc., 1981.

9. Blanchard, Benjamin S., Jr. and E. Edward Lowery. Maintainability Principles and Practices. New York: McGraw-Hill Book Company, 1969.

10. Department of Defense. Sampling Procedures and Tables for Inspection by Attributes. MIL-STD-105D. Washington: Government Printing Office, 19 April 1963.

11. Juran, J. M. and Frank M. Gryna, Jr. Quality Planning and Analysis. New York: McGraw Hill Book Company, 1980.

12. Kniss, James R. "Developing Reliable Systems: Fact Versus Fiction," National Defense, 68: 24-27 (March 1984).

13. Myers, Richard H., Kam L. Wong, and Harold M. Gordy. Reliability Engineering for Electronic Systems. New York: John Wiley and Sons, Inc., 1964.

14. Nelson, Wayne. Applied Life Data Analysis. New York: John Wiley and Sons, Inc., 1982.

15. Russ, Lt Gen Robert D. "Fourth Wheel on the Acquisition Wagon," Air Force Magazine, 12: 122-125 (March 1985).

16. Smith, Dr. R. M. and others. Reliability Data Acquisition and Analysis Techniques System Documentation. BDM/H-850881-TR, Draft. The BDM Corporation, Huntsville AL, 1985.

17. Talbott, Lt Col Carlos M., Jr. Graphical Techniques for Maintenance Planning. PhD Dissertation. School of Engineering and Applied Science, George Washington University, Washington DC, February 1986.

18. Tiku, M. L. "Goodness of Fit Statistics Based on the Spacings of Complete or Censored Samples," Australian Journal of Statistics, 22: 260-275 (Fall 1980).

19. Trapp, R. D. and others. An Approach for Assessing Missile System Dormant Reliability, Final Report. The BDM Corporation, Albuquerque NM, 1981.

VITA

Captain Albert E. Sisk was born on 16 April 1947 in Joplin, Missouri. He graduated from high school in Hays, Kansas in 1965. He enlisted in the Air Force in May 1966 and was released from active duty in March 1970. He attended Southern Illinois University at Edwardsville and received a Bachelor of Science in Special Education in March 1975. Upon graduation, he was commissioned in the Air Force through the ROTC program. He was called to active duty in July 1975 and completed Operational Readiness Training for the Minuteman III ICBM weapon system in October 1975. He then served as a Missile Launch Officer at F. E. Warren AFB, Wyoming until September 1979. He then served as a Test Manager in SAC's TOPHAND program for the Minuteman Test Launch Program at Vandenberg AFB, California until August 1983. He then served as a SAC Liason for the Minuteman weapon system at Hill AFB, Utah until he entered the School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB OH, in May 1985.

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Thesis Advisor: Phillip E. Miller, Major, USAF
Assistant Professor of Logistics Management

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This research described the failure distributions of selected Minuteman III guidance system electronic cards and was the first attempt to use the Total Time on Test graphical technique to detect failure patterns. The data analysis was performed by using a Zenith 100 computer program that performed the Total Time on Test calculations and the Reliability Data Acquisition and Analysis Techniques software package.

The objectives of the research were to 1) describe the failure distributions of selected Minuteman III electronic cards, 2) determine if the corresponding hazard function demonstrated infant mortality, useful life, or wearout, and 3) suggest management strategies to deal with wearout or infant mortality.

Five individual cards were selected and the first three lifetimes of each card were examined. Nine of the fifteen cards indicated an exponential failure distribution, the other six were identified as either a Weibull or a normal failure distribution.

The results of this research indicate that some of the lifetimes did show signs of wearout; however, it was determined that no management actions were required because of the large mean lifetimes of the cards affected.

END

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DTIC